PRACTICAL DESIGN OF SMALL MOTORS AND TRANSFORMERS

Edited by

E. MOLLOY

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PRACTICAL DESIGN OF SMALL MOTORS AND TRANSFORMERS

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PRACTICAL DESIGN OF SMALL MOTORS AND TRANSFORMERS

Explaining clearly the Practical Methods to be employed in designing and constructing Small Electric Motors and Small Power Transformers

GENERAL EDITOR
E. MOLLOY
Editor of "Electrical Engineer"

Containing over 100 Diagrams and Photographs and many useful Design Tables

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PREFACE

PROBLEMS arising from the extensive demand for and the use of small electric motors, dynamos and power transformers in modern life form a large part of the everyday work of electrical engineers.

It is the purpose of this book to provide, in a convenient form, sufficient data to enable any engineer to undertake the design, construction and rewinding of small motors and dynamos, and the design and construction of small power transformers for a wide variety of purposes.

The first section of the book covers motors and dynamos, and the second section covers power transformers.

Chapter I deals with the design of direct-current motors and dynamos, since the design of a motor and dynamo of similar output is essentially the same. The subject is treated and data and tables are included so as not to involve the designer in a great deal of calculation.

The information given in Chapter I will also be found invaluable to those who have to rewind a machine when all or part of the windings have been stripped from the cores, leaving little or no clue on which to base the data for the new coils.

Chapters II and III deal with the procedure to adopt when a machine has to be rewound—how to strip it, how to make up the new coils, making the connections, etc. Both copy winding, i.e. rewinding the same as

the original machine, and converting the machine to run on a different voltage and current are covered.

Chapters of special interest describe how to make small motors of the universal and induction fractional horse-power types. We have no doubt that a great many engineers who have access to a small lathe will want to make these motors.

With regard to the second section dealing with small power transformers, here again the design instructions are as free as possible from calculations. Following the instructions given, no difficulty whatever should be experienced in designing and constructing efficient and lasting units for whatever purpose it may be desired to use them.

E. M.

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CHAPTER I

THE DESIGN OF D.C. MOTORS AND DYNAMOS

THE method of designing a motor and a dynamo of similar output is essentially the same. A dynamo is designed to give a certain output in watts (volts × amperes), whereas a motor is to give a certain horse-power output. A motor may be treated as a dynamo having an equivalent output in watts. The horse-power output of a motor in watts is given by multiplying the horse-power by 746. Thus, a motor of ½ h.p. has an equivalent output of 373 watts.

The Starting-point.

The main purpose of this chapter is to determine the size of the armature and field magnet and to show how the winding data is calculated. It will be assumed that the constructor wishes to build a machine of a certain output.

When the output of the proposed dynamo or motor has been determined from requirements, the size of the armature, which is the starting point, may be found from Tables I–IV. The armature sizes given are only average values and cannot be taken as definite without further investigation. While the outputs shown are easily developed by the given armature sizes, a higher output can be obtained by careful design. It is not possible to give exact sizes for armatures in relation to

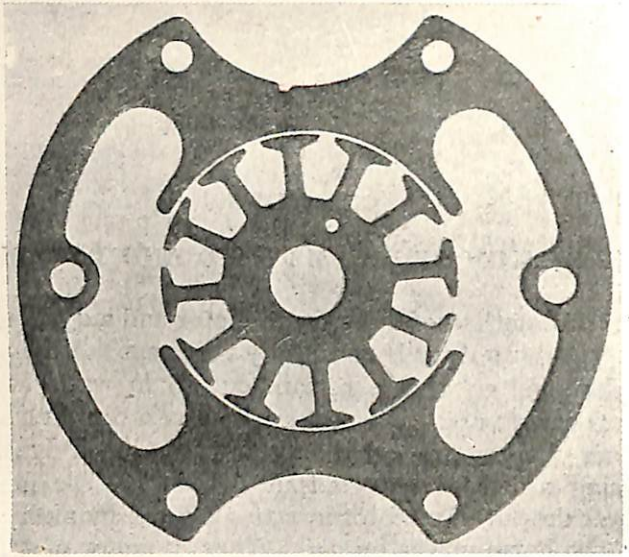


FIG. 1.—AN ARMATURE AND FIELD MAGNET STAMPING OF THE TYPICAL DESIGN WHICH IS DEALT WITH IN THE TEXT.

The armature is $1\frac{23}{32}$-inch diameter with 12 semi-closed slots. The armature spindle hole is $\frac{7}{16}$-inch diameter. The small hole in the armature stampings and the semi-circular nick in the field stampings line up when the stampings are assembled. The field stampings are Sankey's Lohy's iron and the armature stampings are Sankey's Stalloy.

output because the working conditions and the particular design of the stampings are variable factors.

The method of determining the design which is given here is to consider what output is obtainable from a particular design of standard stampings that are likely to give the required output.

Two or Four Poles.

Unless the output of the intended machine is to exceed 500 watts, there is little to gain by constructing a four-pole field magnet. It is possible to obtain a larger output from a four-pole machine than from a

TABLE I

SIZES AND OUTPUTS OF TWO-POLE DYNAMOS

Output (Watts).	Armature Length and Diam. (Inches).	Speed R.P.M.	Field Watts (approx.).
12	1¼	4,000	15
20	1½	3,750	20
35	1¾	3,500	30
45	2	3,000	35
60	2¼	2,750	35
80	2½	2,500	40
100	2¾	2,300	40
130	3	2,100	40
200	3¼	2,000	50
275	3½	2,000	55
350	3¾	1,850	60
450	4	1,800	60
600	4¼	1,750	70
750	4½	1,700	80
820	4¾	1,650	90
1,000	5	1,600	100
1,100	5¼	1,500	100
1,200	5½	1,400	100
1,300	5¾	1,300	100
1,400	6	1,200	100

two-pole machine of the same size. This is partly because the span of coils of the four-pole armature is approximately half the span of the two-pole windings. This gives shorter end windings, which makes for higher efficiency because the end windings of the armature are inactive and merely add resistance to the armature. Another reason is that the field excitation is more efficient, because the ampere-turns are obtained with four smaller diameter coils instead of with the two larger coils of the bi-polar dynamo or motor. Hence less power is required for excitation of the field.

TABLE II

SIZES AND OUTPUTS OF FOUR-POLE DYNAMOS

Output (Watts).	Armature Diameter (Inches).	Armature Length (Inches).	Speed R.P.M.	Field Watts (approx.).
60	$2\frac{1}{2}$	$1\frac{7}{8}$	2,500	35
80	$2\frac{3}{4}$	$2\frac{1}{8}$	2,300	40
100	3	$2\frac{1}{4}$	2,100	40
160	$3\frac{1}{4}$	$2\frac{1}{2}$	2,000	40
250	$3\frac{1}{2}$	$2\frac{5}{8}$	2,000	50
300	$3\frac{3}{4}$	$2\frac{3}{4}$	1,850	60
470	4	3	1,800	70
670	$4\frac{1}{4}$	3	1,750	80
800	$4\frac{1}{2}$	3	1,700	90
1,000	$4\frac{3}{4}$	$3\frac{1}{2}$	1,650	100
1,300	5	$3\frac{3}{4}$	1,600	100
1,500	$5\frac{1}{4}$	4	1,500	100
1,650	$5\frac{1}{2}$	$4\frac{1}{8}$	1,400	100
1,850	$5\frac{3}{4}$	4	1,300	100
2,000	6	$4\frac{1}{2}$	1,200	100

Procedure in Design.

The procedure in the design of a dynamo or motor is best understood by considering an actual example. Suppose it is proposed to construct a shunt-wound dynamo with an output of 6 volts 6 amperes, or 36 watts.

The Stampings.

Table I gives an armature diameter of $1\frac{3}{4}$ inches for an output of 35 watts, so that this size is provisionally fixed for the machine. Fig. 1 shows an armature and bi-polar field magnet stamping to suit these requirements. The use of stampings for both field magnet and the armature is advised not only on the score of efficiency but also for simplicity of construction, which

is thereby obtained. A laminated field magnet is less than half the weight of a cast-iron one designed to carry the same total flux.

The Field Magnet.

Since in a bi-polar machine the length of the armature is made equal to the diameter, the length of the assembled field magnet will be $1\frac{3}{4}$ inches. The stampings are 0·02-inch thick, so that the field magnet will consist of about 90 stampings.

Before the armature can be considered it is necessary to calculate the field strength in the air gap between the armature and the pole faces. With this object in view the total flux in the magnet itself is first estimated.

Calculation of Field Strength.

For laminated field magnets of Lohy's iron, such as are now being considered, it is possible to work economically at a flux density of 95,000 lines per square inch.

The total flux of the yokes of the magnet is given by area (square inches) × 95,000.

Area of yokes $= 2 \times \frac{1}{4} \times 1\frac{3}{4}$ square inches.

Since the stampings are paper coated the actual area of iron will be:

Area $= 2 \times \frac{1}{4} \times 1\frac{3}{4} \times 0{\cdot}95$ square inches.

Total flux $= 2 \times \frac{1}{4} \times 1\frac{3}{4} \times 0{\cdot}95 \times 95{,}000$ lines $=$ 79,000 lines.

The total flux in each air gap is less than this by about 10 per cent. on account of magnetic leakage. That is to say, some 10 per cent. of the magnetic lines developed will not pass through the armature and are therefore ineffective.

Total flux in air gap $= 79{,}000 \times 0{\cdot}9$ lines
$= 71{,}100$ lines.

Thus a total flux in the air gap of 71,000 lines forms the basis of the calculations for the armature windings. The odd 100 lines may be neglected.

Estimation of Armature Output.

Now that the total flux in each gap is known, it is possible to calculate the armature windings.

If Z = Total conductors in armature slots
E = Voltage of armature
F = Total flux per pole
P = Number of poles
N = Speed of armature, r.p.m.
S = Number of parallel paths in armature, then

$$Z = \frac{E \times 60 \times 10^8 \times S}{F \times P \times N} \text{ conductors.}$$

In the present example:

E = 6 volts
F = 71,000 lines
P = 2
N = 3,500 r.p.m. (from Table I)
S = 2 for a two-pole machine,

$$\therefore Z = \frac{6 \times 60 \times 10^8 \times 2}{71{,}000 \times 2 \times 3{,}500} \text{ conductors}$$

$$= 145 \text{ conductors.}$$

This does not take into account that the windings cause a drop in volts, which must be allowed for by adding extra turns to the armature. Allow 10 per cent. extra conductors for small machines. For larger machines the actual armature resistance must be worked out. The total armature conductors, therefore,

$$= 145 \times 1{\cdot}1$$
$$= 160.$$

Since there are 12 slots, 14 wires in each slot are required, which means that there will be 12 coils of 7 turns each. The extra voltage developed by the increase of total conductors from 160 to 168 is negligible.

The accurate determination of the number of armature conductors is possible by using the following:

$$Z = \frac{10^8 \, E \times S}{(0{\cdot}0167 \; F \; PN) - (0{\cdot}0139 \times 10^8 \; I l R)}$$

Where E = Terminal volts at full load
S = Number of parallel armature circuits
F = Total flux per pole
P = Number of poles
N = r.p.m.
I = Full load current
l = Length of mean turn of armature coils (inches)
R = Resistance of wire ohms per yard.

In the present example:

$$Z = \frac{10^8 \times 6 \times 2}{(0{\cdot}0167 \times 71{,}000 \times 2 \times 3{,}500) - (0{\cdot}0139 \times 10^8 \times 7{\cdot}5 \times 7{\cdot}2 \times 0{\cdot}01328)}$$

$$= \frac{12 \times 10^8}{0{\cdot}0167 \times 4{\cdot}95 \times 10^8 - 0{\cdot}0102 \times 10^8}$$

$$= \frac{12 \times 10^8}{10^8 \; (0{\cdot}0832 - 0{\cdot}0102)}$$

$$= \frac{12}{0{\cdot}073}$$

$$= 165 \text{ conductors.}$$

Calculation of Field Windings.

The calculation of the magnetizing ampere-turns is the same whether a machine is shunt or series wound,

TABLE III

TWO-POLE MOTORS

H.P.	Armature Diameter and Length (Inches).	Speed R.P.M.	Equivalent Watts.
$\frac{1}{30}$	$1\frac{1}{4}$	4,000	25
$\frac{1}{20}$	$1\frac{1}{2}$	3,750	37·3
$\frac{1}{12}$	$1\frac{3}{4}$	3,500	62·5
$\frac{1}{10}$	2	3,000	74·6
$\frac{1}{8}$	$2\frac{1}{4}$	2,750	93·5
$\frac{1}{6}$	$2\frac{1}{2}$	2,500	125
$\frac{3}{10}$	$2\frac{3}{4}$	2,300	140
$\frac{1}{4}$	3	2,100	185
$\frac{1}{3}$	$3\frac{1}{4}$	2,000	250
$\frac{1}{2}$	$3\frac{3}{4}$	1,850	373
$\frac{3}{4}$	$4\frac{1}{4}$	1,750	625
1	$4\frac{1}{2}$	1,700	746
$1\frac{1}{4}$	$4\frac{3}{4}$	1,650	935
$1\frac{1}{2}$	5	1,600	1,120
$1\frac{3}{4}$	$5\frac{1}{2}$	1,400	1,310
2	6	1,200	1,500

although the two types of windings are themselves different. The magnetizing power is measured in ampere-turns and is called the magneto-motive force of the magnet. The magneto-motive force of a magnetic circuit gives rise to a " current " of magnetic lines against the opposition of the magnetic resistance of the iron and air gaps, in a similar way to which the electro-motive force or volts of an electric circuit causes an electric current against the opposition of the electrical resistance of the wire.

The estimation of the magnetizing force required to produce a certain flux in a particular magnetic circuit is simplified to measuring the length of the magnetic

TABLE IV

FOUR-POLE MOTORS

H.P.	Armature Diameter (Inches).	Armature Length (Inches).	Speed R.P.M.	Equivalent Watts.
$\frac{1}{8}$	$2\frac{1}{2}$	$1\frac{7}{8}$	2,500	93·5
$\frac{1}{6}$	$2\frac{3}{4}$	$2\frac{1}{8}$	2,300	125
$\frac{1}{4}$	3	$2\frac{3}{4}$	2,200	185
$\frac{1}{2}$	$3\frac{3}{4}$	$2\frac{3}{4}$	1,850	373
$\frac{3}{4}$	4	$3\frac{1}{2}$	1,800	625
1	$4\frac{1}{4}$	3	1,750	746
$1\frac{1}{2}$	$4\frac{1}{2}$	$3\frac{3}{8}$	1,700	935
$1\frac{1}{2}$	$4\frac{3}{4}$	$3\frac{1}{2}$	1,650	1,120
$1\frac{3}{4}$	5	$3\frac{1}{2}$	1,600	1,310
2	$5\frac{1}{4}$	4	1,500	1,500
$2\frac{1}{4}$	$5\frac{1}{2}$	$4\frac{1}{8}$	1,400	1,680
$2\frac{1}{2}$	$5\frac{3}{4}$	$4\frac{1}{4}$	1,300	1,870

paths and calculating the flux densities in the different parts of the circuit.

When these two values are known the ampere-turns is estimated from Table V.

Estimation of the Magnetizing Force.

The estimation of the magnetizing force required for the 36-watt dynamo, which is being considered as an example, is done as follows.

The flux density in the yoke is to be 95,000 lines. Table V gives 33 ampere-turns per inch for the density in Lohy's iron, which is the material from which the field stampings are made.

The average length of magnetic path in the yoke is $4\frac{1}{4}$ inches, therefore:

Yoke ampere-turns $= 4\frac{1}{4} \times 33$

$= 140$ per pole, or 280 total.

The total flux in the air gap is 71,000 lines. The area

TABLE V

MAGNETIZING FORCE REQUIRED FOR FIELD MAGNETS

Lines per Square Inch.	Ampere-Turns per Inch.			
	Air.	Cast Iron.	Lohy's Iron.	Stalloy.
10,000	3,200	11	—	—
15,000	4,800	14·5	—	—
20,000	6,400	19·5	—	—
25,000	8,000	25·5	—	—
30,000	9,600	33·5	3	2·3
35,000	11,200	44·0	3·5	2·8
40,000	12,800	80·0	4·6	3·3
45,000	14,400	—	5·1	4·0
50,000	16,000	—	6·1	4·6
55,000	17,600	—	7·1	5·3
60,000	19,200	—	8·6	6·6
65,000	20,800	—	10·0	8·1
70,000	22,400	—	12·7	11·2
75,000	—	—	51·3	14·7
80,000	—	—	17·8	15·7
85,000	—	—	23·0	20·0
90,000	—	—	25·6	25·4
95,000	—	—	33·0	35·6
100,000	—	—	43·0	55·6
110,000	—	—	127·0	178·0

of the air gap is found, approximately, by adding together the area of the five armature pole faces which cover the field pole face.

$\therefore$ Area of gap $= 5 \times \frac{11}{32} \times 1\frac{3}{4}$ square inches.

$$\text{Density in gap} = \frac{\text{Total flux}}{\text{Area of gap}}$$

$$= \frac{71{,}000 \times 32 \times 4}{5 \times 11 \times 7} \text{ lines per square inch}$$

$= 23{,}600$ lines per square inch.

Total length of gap $= 2 \times 0{\cdot}02$ inches

$= 0{\cdot}04$ inch.

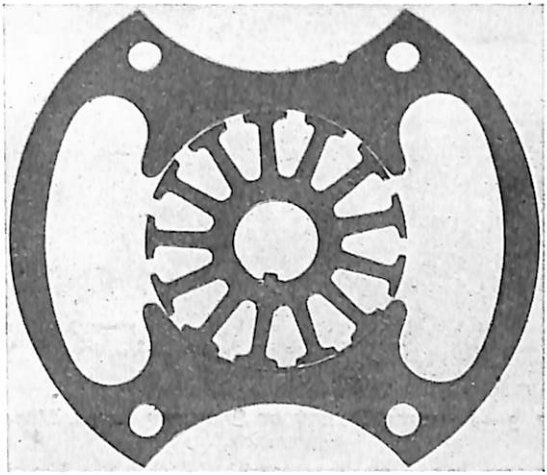


FIG. 2.—A PAIR OF SANKEY'S SMALL MOTOR STAMPINGS.

The armature has a key which is made to fit the keyway in the shaft. The armature is $1\frac{9}{16}$-inch diameter, $\frac{1}{2}$-inch hole. The magnet yoke is $\frac{7}{32}$-inch wide and the air gap 0·01 inch. The armature slots are of a particularly good design.

The ampere-turns per inch for a flux density in air of 23,600 lines per square inch is found by multiplying the density by 0·32.

$$\therefore \text{Ampere-turns} = 0{\cdot}32 \times 23{,}600$$
$$= 7{,}550 \text{ per inch}$$
$$\text{Total ampere-turns} = 7{,}550 \times 0{\cdot}04$$
$$= 302.$$

Finding the Ampere-turns Required to Drive the Flux through the Armature.

It now remains to find the ampere-turns required to drive the flux through the armature. This may be sufficiently accurately estimated by multiplying the sum of the ampere-turns for the yoke and the air gaps by 1·05 to give the total ampere-turns for the whole

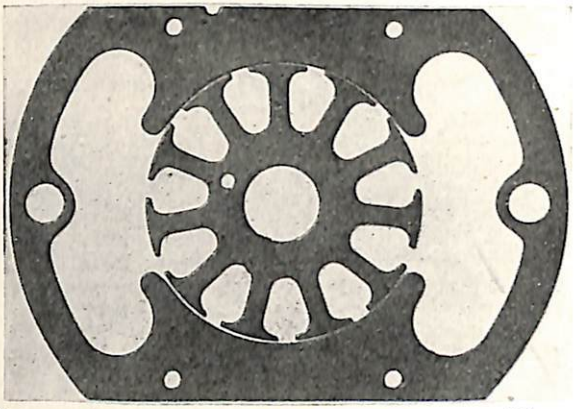


FIG. 3.—ANOTHER DESIGN OF SANKEY'S SMALL MOTOR STAMPINGS.

The armature is $1\frac{9}{16}$-inch diameter with $\frac{7}{16}$-inch hole. The air gap is 0·01 inch. The width of the yoke is $\frac{7}{32}$-inch.

magnetic-circuit. For larger machines, however, the percentage of ampere-turns for the armature is higher and must be calculated. In the present example this is done as follows:

The area of the armature teeth, neglecting the pole extensions

$$= 5 \times \tfrac{3}{32} \times 1\tfrac{3}{4} \text{ square inches.}$$

$$\text{Density in teeth} = \frac{71{,}000 \times 32 \times 4}{5 \times 3 \times 7}$$

$$= 86{,}500 \text{ lines per square inch.}$$

$$\text{Length of teeth} = 2 \times \tfrac{3}{8} \text{ inches}$$

$$= \tfrac{3}{4} \text{ inch.}$$

$$\text{Ampere-turns (Stalloy)} = \tfrac{3}{4} \times 20$$

$$= 15 \text{ ampere-turns.}$$

$$\text{Area of armature core} = 2 \times \tfrac{9}{32} \times 1\tfrac{3}{4} \text{ square inches.}$$

$$\text{Flux density in core} = \frac{71{,}000 \times 32 \times 4}{2 \times 9 \times 7}$$

$$= 72{,}000 \text{ lines per square inch.}$$

Length of magnetic path in core = 1 inch
∴ Ampere-turns (Stalloy) = 1 × 13.

The summary of the above calculations is as follows :

Ampere-turns for yokes	=	280
,, ,, air gaps	=	302
,, ,, armature teeth	=	15
,, ,, armature core	=	13
Total ampere-turns	=	610

Field Winding.

The diameter of the wire for the wire of the field winding of a shunt machine is found from the formula :

$$D = \sqrt{\frac{0{\cdot}0000001AT\mathit{l}}{E}}$$

Where D = Diameter of wire (inches)
AT = Ampere-turns
l = Length of mean turn of field coil (inches)
E = Voltage across coils.

In the present example :

AT = 610
l = 8·3
E = 6

$$\therefore D = \sqrt{\frac{0{\cdot}0000001 \times 610 \times 8{\cdot}3}{6}}$$

= 0·029 inch.

The nearest standard wire gauge to this figure is 22, which has a diameter of 0·028 inch. The current which can safely be passed by this size of wire at 2,500 amperes per square inch is 1·5 amperes.

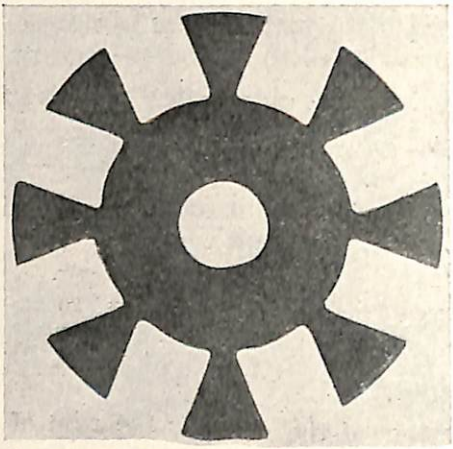


FIG. 4.—A TYPICAL DESIGN OF SLOTTED DRUM ARMATURE.
This open slot type is more suitable for form winding. Binders are used instead of slot wedges to retain the windings.

The number of field turns can now be determined.

$$\text{Turns} = \frac{\text{Ampere-turns}}{\text{Amperes}}$$

$$\therefore \text{Turns} = \frac{610}{1{\cdot}5}$$

$$= 406.$$

The field coils will therefore consist of two windings of 203 turns each of 22 S.W.G. enamel-covered wire or double silk-covered wire. Double cotton-covered wire is not to be recommended for small field coils on account of the extra space which it occupies and it will generally be found impossible to accommodate the required number of turns on standard designs of stampings.

Gauge of Armature Wire.

Now that the field current has been determined it is possible to calculate the total current output of the armature. The total output from the armature is the net output plus the field current. The net output is 6 amperes and the field amperes is 1·5. The total output of the armature is therefore 7·5 amperes. The gauge of wire for the armature depends on two factors: (1) the current in the armature; (2) the current density at which it is safe to work with the type of armature under consideration. The current density for a naturally ventilated armature may be taken at 2,500 amperes per square inch where the machine is to run continuously.

On page 47 is given a table showing the gauges of wire suitable for various armature currents. Now each conductor in a two-pole motor or dynamo carries only half the total current. Thus each conductor carries 3·75 amperes. The suitable S.W.G. is, therefore, No. 18.

Armature Slots.

It now remains to see whether 14 insulated wires of 18 S.W.G. can be accommodated in each slot. The winding space in each slot is 0·07 square inch. To find the area which can be usefully occupied by conductors, divide this area by 1·4. The effective area is, therefore, 0·05 square inch.

The maximum number of conductors of 18 S.W.G. double cotton-covered wire which can be wound in 1 square inch is 286. (See Table XII, page 174.) Therefore, in 0·05 square inch:

$$\text{Maximum conductors} = 0{\cdot}05 \times 286$$
$$= 15.$$

Thus with 14 conductors per slot there will be sufficient room to place a stiff wedge between the top of the winding and the top of the slot, which is the usual method of retaining the windings in this type of armature.

Maximum Output.

It will be seen from the previous paragraph that by winding 14 conductors per slot, the maximum possible output is not realized. If it is sufficient, then no harm is done by not filling the slots to the best advantage. If, however, the maximum possible output is desired, the armature is wound with single silk-covered wire. To maintain the output at 6 volts the number of turns is kept the same. A gauge of wire is chosen which will wind so as to fill the slots. Since the slot area is 0·05 square inch the wires per square inch will be 280, i.e. $\frac{14}{0{\cdot}05}$. The heaviest gauge of single silk-covered wire which can be put on is therefore 17, which winds 287 conductors per square inch. (See Table XII, page 173.) This gauge of wire will permit an output of 12 amperes total armature current or an output current of 10·5 amperes. The maximum output is therefore $10{\cdot}5 \times 6 = 63$ watts.

Cast-Iron Field Magnets.

The calculation of the windings for cast-iron field magnets is the same as for laminated ones, but different flux densities and magnetizing forces have to be observed. Suppose the dynamo, which has just been considered, were to have a cast-iron magnet. The magnet would have to be considerably larger than the laminated one to obtain the same total flux in the air gaps. The overall size of the magnet would be in-

creased to 5 inches, which would increase the mean flux path to about 6 inches.

The most economical flux density for cast-iron field magnets, in small sizes, is 35,000 lines per square inch. The magnetizing force required for this is given in Table V as 44 ampere-turns per inch. The total ampere-turns for the magnet is therefore :

$$2 \times 6 \times 44 = 528 \text{ ampere-turns.}$$

The rest of the circuit is already found to need 330 ampere-turns, so that the total is 858. This means a wire diameter of 0·036 or 20 S.W.G. The current for this gauge of wire is 2·5 amperes as against 1·5 amperes of the laminated magnet windings.

Motor Design.

The calculation of the shunt field coils of a motor are exactly the same as for a dynamo. The armature design is really the same, although it is treated in a slightly different manner.

The starting point in the design of a motor is the formula :

$E - V = IR.$

Where E = Supply volts
V = Armature voltage, or back E.M.F.
I = total armature current
R = armature resistance.

It is evident from this formula that it is necessary to find the armature resistance, in order that the speed may be predetermined.

How Armature Resistance is Found.

Suppose, as an example, the stampings previously considered as a dynamo are to be used for a 230-volt motor of $\frac{1}{12}$ h.p. output. The equivalent output of

the armature is 62·5 watts. The current in the armature is the watts divided by the back E.M.F. voltage, not the mains voltage. In order to make a trial calculation it is necessary to assume a percentage drop in the armature. If this is taken as 10 per cent. the armature or back E.M.F. voltage is 207 volts. On this assumption the armature resistance is found as follows:

$$I = \frac{\text{Watts}}{V}$$

$$= \frac{62{\cdot}5}{210}$$

$$= 0{\cdot}3 \text{ ampere.}$$

The resistance of the armature is found by dividing the effective E.M.F. of the armature, which is the difference between the mains voltage and the back E.M.F., by the armature current. The armature resistance is therefore:

$$R = \frac{230 - 207}{0{\cdot}3}$$

$$= 76{\cdot}7 \text{ ohms.}$$

Number of Armature Conductors.

The number of armature conductors is calculated from the same formula as for finding the number of dynamo armature conductors. Instead of E the output voltage, is substituted V, the back E.M.F. voltage, thus:

$$Z = \frac{V \times 60 \times 10^8 \times S}{F \times P \times N}$$

$V = 207$ volts
$F = 71{,}000$ lines
$P = 2$

$$N = 3{,}500 \text{ r.p.m.}$$
$$S = 2$$
$$Z = \frac{207 \times 60 \times 10^8 \times 2}{71{,}000 \times 2 \times 3{,}500}$$
$$= 5{,}000 \text{ conductors, or } 418 \text{ per slot.}$$

As before, with a useful slot area of 0·05 the wire per square inch is $\frac{418}{0{\cdot}05} = 8{,}150$. This corresponds to 35 S.W.G. double silk-covered wire. This gauge of wire will carry the current, 0·15 ampere, at a density of 2,700 amperes per square inch, which is safe.

Calculating Armature Resistance.

It now remains to calculate the armature resistance when wound with 2,500 turns of 35 S.W.G. wire, so that the assumed drop in volts in the armature may be checked. The armature resistance in ohms is given by:

$$R = \frac{Z \times l \times r}{2 \times 36 \times S}$$

Where Z = total conductors
l = mean length of one armature-turn (inches)
r = resistance of wire per yard
S = number of parallel circuits.

In the present example:

$$Z = 5{,}000$$
$$l = 7{\cdot}25 \text{ inches}$$
$$r = 0{\cdot}4338 \text{ ohms}$$
$$S = 2$$
$$R = \frac{5{,}000 \times 7{\cdot}25 \times 0{\cdot}4338}{2 \times 36 \times 2}$$
$$= 109 \text{ ohms.}$$

The increase in resistance from 76·7 ohms, the assumed value, to 109 ohms will result in a lower speed of 3,340 r.p.m. This will give a correspondingly lower horse-power output, actually only 4 per cent. less.

For an accurate determination of the number of armature conductors the following expression is used :

$$Z = \frac{6 \times 10^9 S \ \underline{(E - 1 \times Z \times l \times r)}}{\underline{72 \times S}} \\ F \times p \times N$$

This formula is a combination of the three expressions for the armature voltage, the motor formula and the formula for the armature resistance.

In the present example design :

$$Z = \frac{6 \times 10^9 \times 2 \ \underline{(230 - 0{\cdot}3 \times Z \times 7{\cdot}25 \times 0{\cdot}4338)}}{\underline{72 \times 2}} \\ 71{,}000 \times 2 \times 3{,}500$$

$\therefore Z = 4{,}770$, or 398 per slot.

Series Field Windings.

The examination of series field windings is confined to motors, because the series dynamo has very little practical value. In a series-wound motor the total armature current passes through the field coils, therefore the number of turns on the series field coils is simply found by dividing the ampere-turns by the main current. The gauge of wire is proportioned to carry this current at 2,500 amperes per square inch. The resistance of the coils is then found when the volts drop at full load is estimated. This drop subtracted from the mains voltage gives the voltage at which the armature works at full load.

Suppose for the sake of argument the volts drop in the field coils of a 230-volt series motor is 25 volts,

the volts applied to the armature would be 205 volts. The calculation of the armature winding is then as for a shunt machine of 205 volts input. It is evident from this that a series motor armature, of the same horse-power output as that of a shunt motor, is wound with fewer turns of thicker wire if the mains voltages are the same.

Sources of Loss.

The overall efficiency of a dynamo or motor is dependent on the following losses:

(1) Field excitation watts;
(2) Armature copper loss;
(3) Armature iron loss;
(4) Heating;
(5) Brush contact drop;
(6) Friction of bearings and brushes;
(7) Windage.

The field excitation and armature copper loss or volts drop have been considered. These are definite and can be calculated without much difficulty. The armature iron loss is practically negligible in small machines. Actually the loss amounts to about 1 watt per pound of armature iron at speed of 3,000 r.p.m. The loss due to heating is the extra drop in volts in the armature caused by the rise in resistance as the machine warms up on load. This can be determined only by experiment, because the various factors which determine the actual temperature rise cannot be calculated.

The brush contact drop may be estimated from Table VI, showing the characteristics of dynamo and motor brushes. This loss may be compensated by making a suitable allowance before commencing the armature

TABLE VI.—WORKING DATA OF MORGANITE AND BATTERSEA CARBON BRUSHES

Type.	Specific Resistance (Ohms per Inch Cube).	Contact Drop at Normal Current Density (Volts).	Maximum Commutator Surface Speed (Feet per Minute).	Normal Current Density (Amps. per Square Inch).		Mica.	Brush Pressure (Lb. per Square Inch).	Uses.	Remarks.
				Commutators.	Slip-Rings.				
Link One Morganite	0·00083	0·95	10,000	60	—	Recessed	2	Stationary machines	Silent
Link Five Morganite	0·00075	0·90	10,000	60	—	Recessed	2	Stationary machines	Does not expand with heat
Link HM3 Hard Morganite	0·00062	0·90	10,000	65	75	Recessed	2	Rotary converters	A clean lubricating brush
Link HM5 Hard Morganite	0·00065	0·90	10,000	65	75	Recessed	2	Turbo-exciters and large D.C. machines	Low friction
Link HM6 Hard Morganite	0·00075	0·85	10,000	65	75	Recessed	2	D.C. machines, turbo alternator slip-rings	A good commutating brush
Link CM Copper Morganite	0·000007	0·25	4,000	100	150	Flush	8 for car starters	Bronze slip-rings, 6-volt starter motors and very low voltage machines	—
Link CM1S Copper Morganite	0·000011	0·25	5,000	100	150	Flush	2	D.C. machines and slip-rings up to 10 volts	Specially suitable for oil lubricated slip-rings
Link CM2 Copper Morganite	0·000008	0·25	5,000	100	150	Flush	2 2½ for slip-rings	D.C. machines and slip-rings up to 10 volts	—
Link CM3H Copper Morganite	0·000013	0·35	6,000	80	100	Flush	3 for slip-rings 8 for car starters	Rotary converter slip-rings, car dynamos and starters	—
Link CM5H Copper Morganite	0·000025	0·50	6,000	75	90	Flush	2 3 for slip-rings	Rotary converter slip-rings, induction motor slip-rings and car dynamos and starters	—
Link CM6 Copper Morganite	0·000110	0·45	5,000	70	90	Flush	2	D.C. machines and induction motor slip-rings up to 50 volts	—

Link A Battersea Carbon	0·0013	1·0	4,000	45	—	Flush	2	Stationary machines	Good lubricating qualities
Link A5 Battersea Carbon	0·0020	1·1	4,000	40	—	Flush	2	Car dynamos	—
Link B Battersea Carbon	0·0011	0·95	4,000	55	70	Flush	2	Machines of all voltages	Suitable where no special commutating difficulties are present
Link B6 Battersea Carbon	0·0013	1·0	4,000	50	65	Recessed	2	Machines of all voltages	—
Link C4 Battersea Carbon	0·0021	1·1	3,000	40	—	Flush	2	500-volt motors	Suitable for hard micas
Link C8 Battersea Carbon	0·0027	0·7	3,000	40	—	Flush	2 3-6½ for traction	Traction and other motors	Suitable where high micas cause blackening
Link EG0 Electro-Graphitic	0·0007	0·95	5,000	65	75	Recessed	2	Car dynamos and low voltage machines	A comparatively soft brush
Link EG3 Electro-Graphitic	0·0013	1·0	5,000	55	65	Recessed	3-6½ for traction	Traction motors and A.C. commutator motors	A mechanically strong brush, suitable for contacts subject to violent sparking
Link EG4 Electro-Graphitic	0·0014	0·90	4,000	55	65	Flush	3-6½ for traction	Traction motors and A.C. commutator motors	Similar characteristics to Link EG3
Link EG10 Electro-Graphitic	0·0014	1·2	7,000	60	—	Recessed	2½	A.C. commutator motors, and D.C. machines with widely fluctuating loads	—
Link EG11 Electro-Graphitic	0·0013	1·0	8,000	60	—	Recessed	2½	High speed rotary converters, and traction motors	—
Link EG12 Electro-Graphitic	0·0014	1·2	8,000	60	—	Recessed	2½	High speed converters and dynamos	Suitable where load and commutating conditions are severe

calculations. This loss is negligible in high-voltage machines.

Losses due to the friction of brushes and bearings are a source of considerable loss in small machines, and can be determined only by trial. Small machines should invariably have ball bearings and low voltage machines of less than $\frac{1}{4}$ h.p. should have copper gauze brushes.

Windage is another loss which cannot be predetermined. It does not affect the design of dynamos, but lowers the horse-power output of motors.

Overall Efficiency of Small Motors.

The overall efficiency of small motors of good design is given in the following table:

H.P.	Efficiency.	H.P.	Efficiency.
$\frac{1}{30}$	0·4	$\frac{1}{6}$	0·64
$\frac{1}{20}$	0·5	$\frac{1}{4}$	0·72
$\frac{1}{16}$	0·52	$\frac{1}{2}$	0·76
$\frac{1}{12}$	0·56	1	0·81
$\frac{1}{10}$	0·6	$1\frac{1}{2}$	0·82
$\frac{1}{8}$	0·62	2	0·83

Calculating Total Motor Current.

In the design of the $\frac{1}{12}$-h.p. motor, which has been considered as an example motor design, the windings are calculated to give an armature output of $\frac{1}{12}$ h.p. When designing a motor of a certain horse-power output at the pulley, the total motor current is first calculated from:

$$I = \frac{\text{B.H.P.} \times 746}{E \times e}$$

Where I = Current in amperes
E = Voltage of mains
e = Efficiency expressed as a decimal.

Thus a $\frac{1}{12}$-h.p. motor working at full load on a 230-volt supply has a total line current of 0·48 ampere.

CHAPTER II

HOW TO REWIND A FORMER-WOUND ARMATURE

WHEN a hand-wound armature winding is defective it must be completely rewound, because the end windings overlap one another ; but it is sometimes possible to repair a former-wound armature by replacing only the defective coils. It is not possible to remove any one coil without injury, when the armature has been impregnated and baked, after the former-wound coils have been put on.

The example described here is a 100-watt armature designed to run in bi-polar fields. It has thirteen armature slots and twenty-six commutator segments. Although a former-winding does not give such a high electrical efficiency as a hand-wound one of this size to run in bi-polar fields, the former winding is used on account of its greater mechanical strength and its superior insulation. This type of armature is found chiefly on car dynamos. Fig. 5 shows the difference between a hand-wound and a former-wound armature of the same size.

Stripping the Armature.

The first step in dismantling the armature is to saw through the binders which hold the coils in the slots and also secure the end windings. These are cut

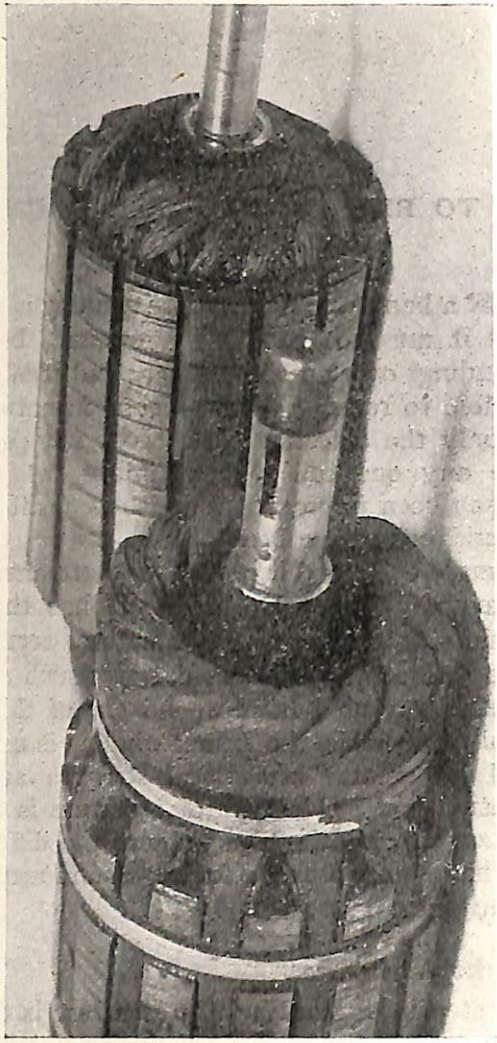


FIG. 5.—A FORMER-WOUND AND HAND-WOUND ARMATURE OF THE SAME SIZE.
Showing the difference in the appearance of the two methods of winding. The former winding is on the left.

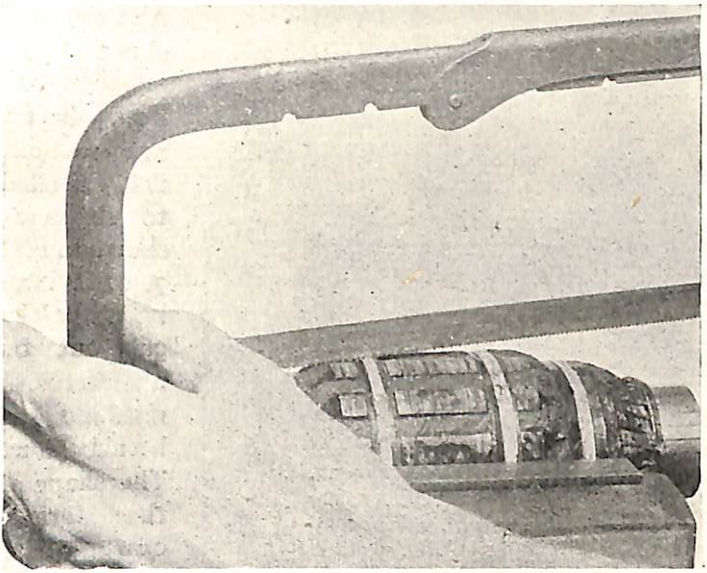


FIG. 6.—SAWING OFF THE BINDERS FROM THE ARMATURE. This is the first step to take in order to remove the old coils.

through with a hacksaw, as shown in Fig. 6, taking care not to damage the armature core. After removing the binders about half of the coils are cut out. Save one coil as near as possible intact with tape to serve as a guide when making the former. The armature, thus partially stripped, is put on one side until a trial coil has been made.

Making the Former.

Take the best one of the coils just removed, flatten it out and shape a piece of wood to fit inside the coil. This is the core of the former. The wood from which this piece is made must be just thinner than the armature slots so as to obtain the correct coil proportions.

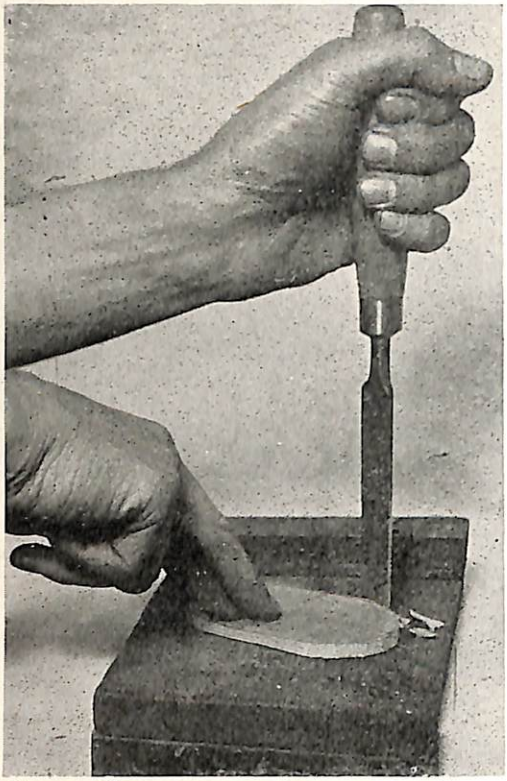


FIG. 7.—CHISELLING THE PARTS OF THE FORMER TO SHAPE.

These may be cut out on a fretwork machine or band saw if available.

After the shape of the former coil has been marked out it is chiselled to shape as shown in Fig. 7, or it may be quickly cut out on a fretwork machine or band saw. The shape of the former centre-piece is shown in Fig. 10. The two long sides represent the length of the armature slots, and the V-end pieces, the end windings.

The Next Step.

After making this part of the former, two cheeks are next prepared from $\frac{1}{4}$-inch plywood. These are made the same shape as the core and sufficiently larger to contain the winding. The three sections of the former are now screwed together so that one cheek

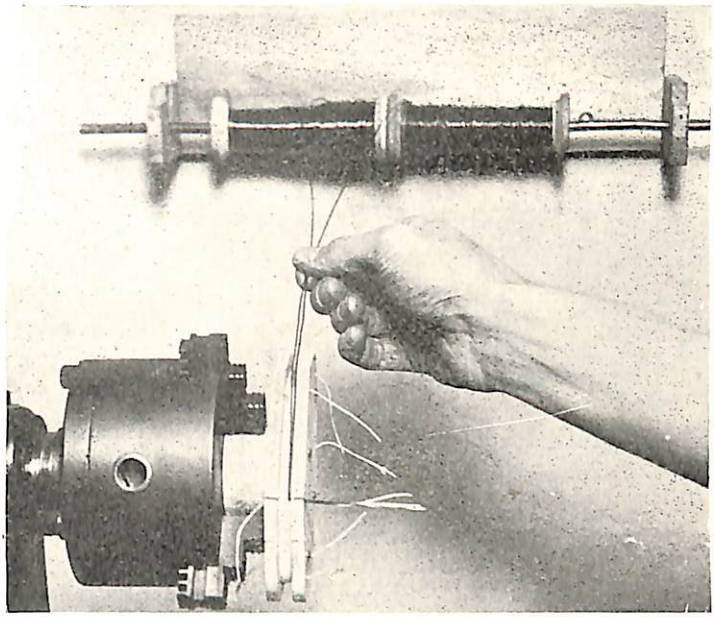


FIG. 8.—HOW TO START WINDING A COIL.

Showing the method of winding a duplex coil. Note the pieces of thread in position for tying up the coil when finished.

is removable. Several saw-cuts are then made round the edge of the former to permit the tying-up of the coil with thread before its removal from the bobbin. By referring to the partly stripped armature, notice at which points the coil ends are brought out and arrange two of the slots in the former to correspond with these. Screw a round boss on the fixed cheek of the former to form a chucking-piece for winding (see Fig. 9). Smooth off the winding space on the former with fine glasspaper and slightly round the inside edges of the cheeks and the bobbin is ready for use.

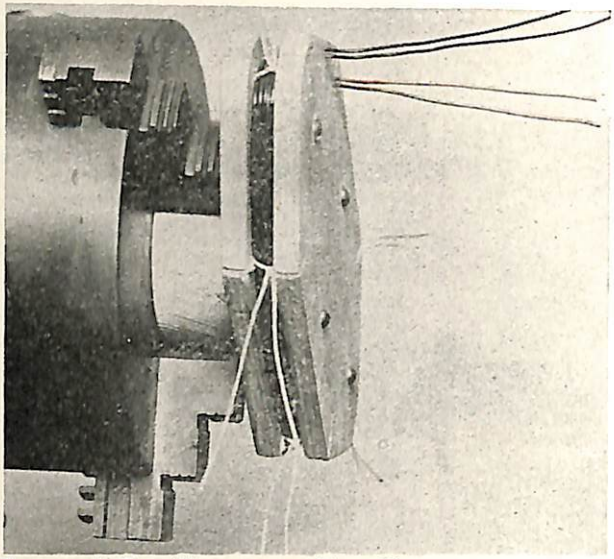


FIG. 9.—A COIL WOUND AND TIED UP BEFORE REMOVAL FROM THE FORMER.

How to Wind the Coils.

The coils for the particular armature under consideration must each have two sections, because the commutator has twice as many sections as the armature. Where the number of armature slots is the same as the number of commutator segments, each coil has only a single winding, and for an armature of three times the number of commutator segments, the coils are wound with three equal sections.

Where to Start the Wire.

Before winding any wire on the former, a piece of thread is put into each slot of the former, as indicated in Fig. 8. The wire is then started on the bobbin with the end coming through the slot in the former, which

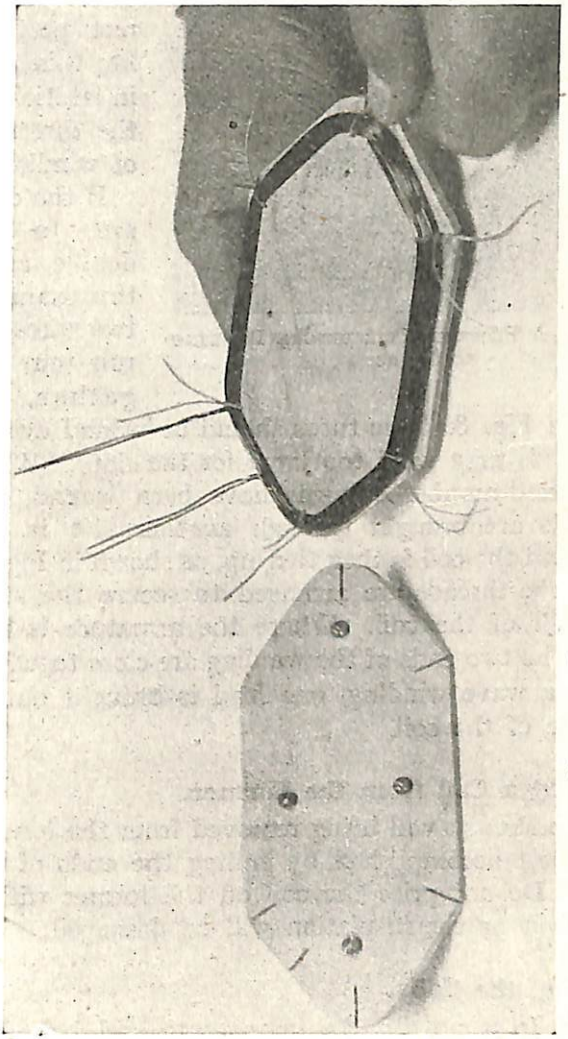


FIG. 10.—REMOVING A COIL FROM THE FORMER.
The leads are tied together so that they do not lose their location when the coil is taped up.

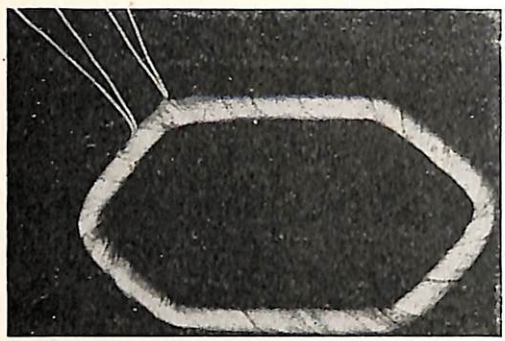


FIG. 11.—A FINISHED COIL BEFORE BENDING TO SHAPE.

gives the correct position for this lead in relation to the direction of winding.

If the coils are to be double, as in this example, two wires are run on together, as shown in Fig. 8. The turns should be wound evenly or the coils may wind too large for the slots. When the required number of turns have been wound, the end leads are brought through another slot in the former and the coil is then tied up, as shown in Fig. 9. Two of the threads are arranged to secure the start and finish of the coil. Where the armature is lap-wound, the two ends of the winding are close together, but for a wave winding, one lead is brought out at each side of the coil.

Removing a Coil from the Former.

Fig. 10 shows a coil being removed from the former. This is best accomplished by pulling the ends of the thread. Do not prise the coil off the former with a screwdriver or the insulation will be damaged.

Insulating the Coils.

Where it is possible to impregnate and bake the coils before putting them on the armature, they may be covered with adhesive tape or empire tape. When

the armature is to be impregnated as a whole, the coils are covered with cotton or silk tape so that the varnish may readily penetrate the coils. Where the coils are wound with enamel-covered wire there is no need for impregnation, because this kind of insulation is non-hydroscopic.

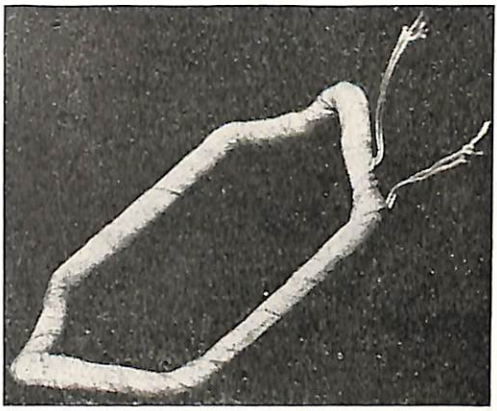


FIG. 12.—A COIL BENT TO SHAPE READY FOR ASSEMBLING ON THE ARMATURE.

The coils are bent by twisting the apex of the ends between the thumb and forefinger.

Fig. 11 shows a coil taped up before being bent to shape.

Shaping the Coils.

After winding one coil, it is taped up and tried on the partly dismantled armature, as shown in Fig. 13. If the length of the coil is found correct, the remainder of the coils may be finished off. If the test coil is lifted carefully from the slots, it will serve as a guide from which to shape the other coils.

Fig. 12 shows a coil formed to shape. It will be found that where the coil spans nearly half the circumference of the armature, as in the present example, it is impossible to get the coils into position without distorting them somewhat, so that they must be finally shaped in position. Where the machine is a four-pole type,

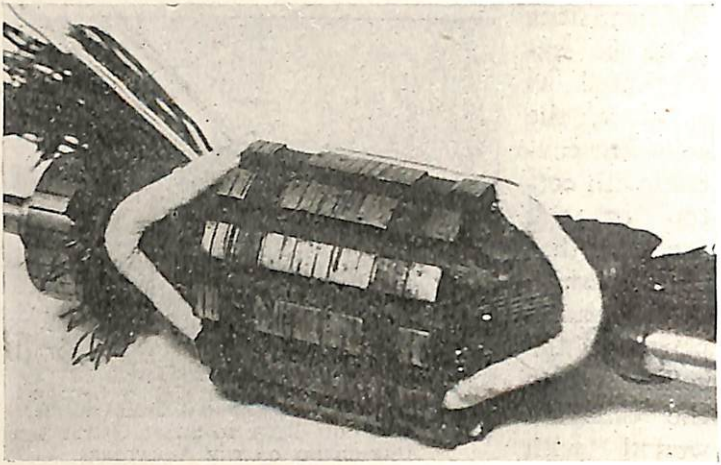


FIG. 13.—TESTING A COIL FOR SIZE.

After the winding of one coil it is tried out on the partially dismantled armature to make sure that it fits.

the coils will span just less than one-quarter of the armature, so that the coils may be accurately shaped before laying them in the slots.

How to Assemble the Coils.

Before the coils are put in, the slot and shaft insulation must be renewed, if necessary. When all the coils have been wound, taped up and bent to the correct shape on the ends, they are put in the slots. The armature illustrated in Fig. 14 has thirteen slots, so that there are thirteen coils. The span of the coils is six slots, so that after five coils have been put in, the sixth to the ninth coils, inclusive, are laid in the top part of the slots over the first to the fourth coils respectively. In order to get the last four coils into position, the first four coils must be temporarily lifted

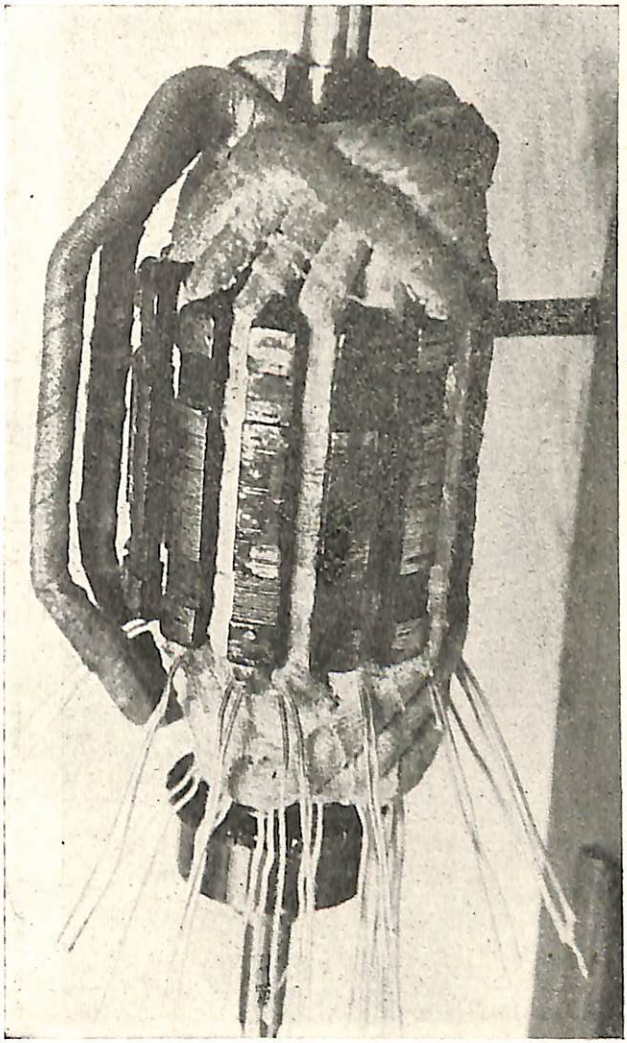


FIG. 14.—THE PARTIALLY ASSEMBLED ARMATURE.
Showing the stage when the last four coils have to be laid under the first four.

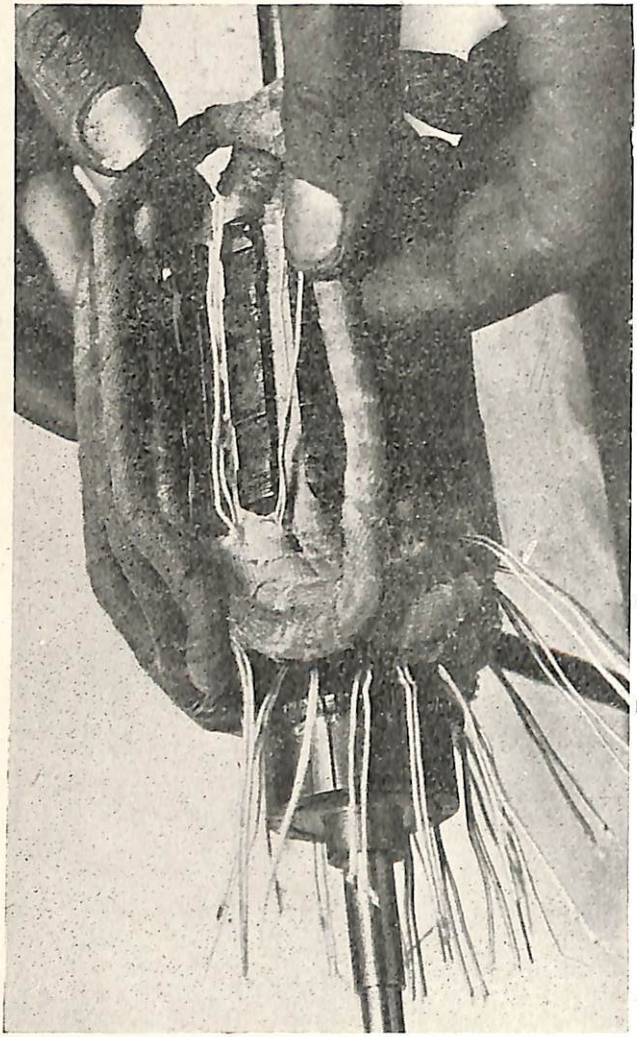


FIG. 15.—INSERTING THE LAST COIL.

In order to do this it is necessary to raise up the first part of the winding. Note how the leads are bent back over the armature.

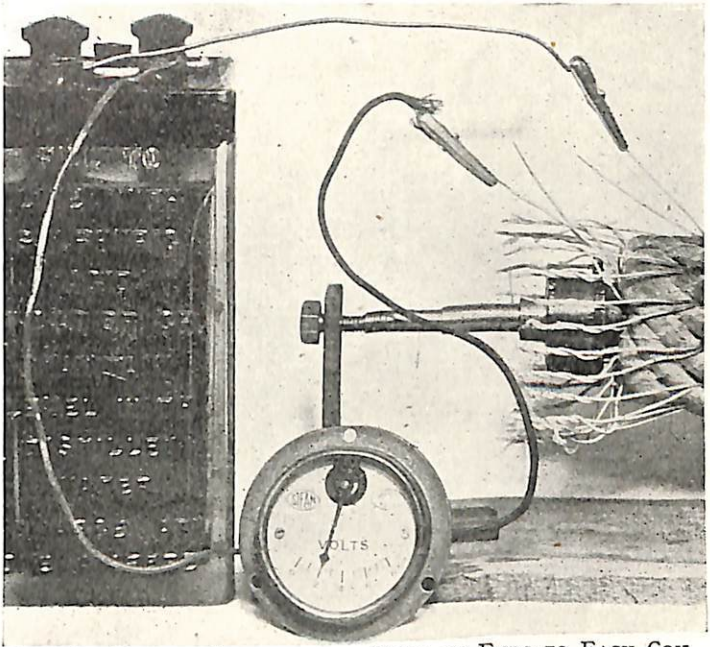


FIG. 16.—HOW TO IDENTIFY THE PAIRS OF ENDS TO EACH COIL.
Showing a simple method when there is more than one section to each coil.

from the slots, as shown in Fig. 14 to enable them to be passed underneath, as it will be seen that to keep the winding symmetrical, the last few coils must occupy the bottom portions of the slots. Fig. 15 shows the last coil being inserted under the first four coils.

Pairing the Leads.

When the coils have more than one winding, as in the present instance, the double leads must be paired up before connecting to the commutator. This is done with the aid of a single cell and a voltmeter, as

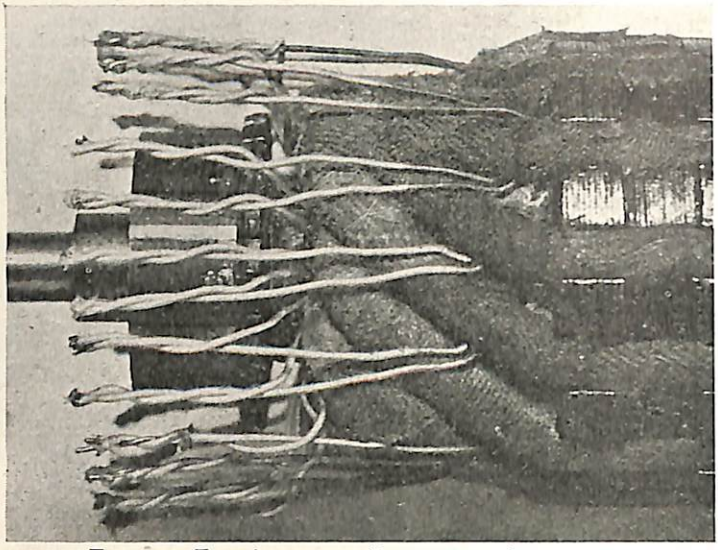


FIG. 17.—THE ARMATURE READY FOR SOLDERING.

Showing the leads of the coils twisted in pairs and placed in order ready for soldering to the commutator.

shown in Fig. 16. As each two leads are paired up, they are twisted together and carefully kept in order round the armature, as shown in Fig. 16. As will be seen from Fig. 15, the starting ends of the winding are brought out near where the coils leave the slots and the finishing ends are brought up from under the ends. This keeps the ends quite distinct and electrically separated.

Connecting to the Commutator.

After the coil ends have been twisted in pairs, the start of one coil is connected to the finish of the next all the way round the armature, so as to form twenty-six pairs of wires. Each coil is treated as though it

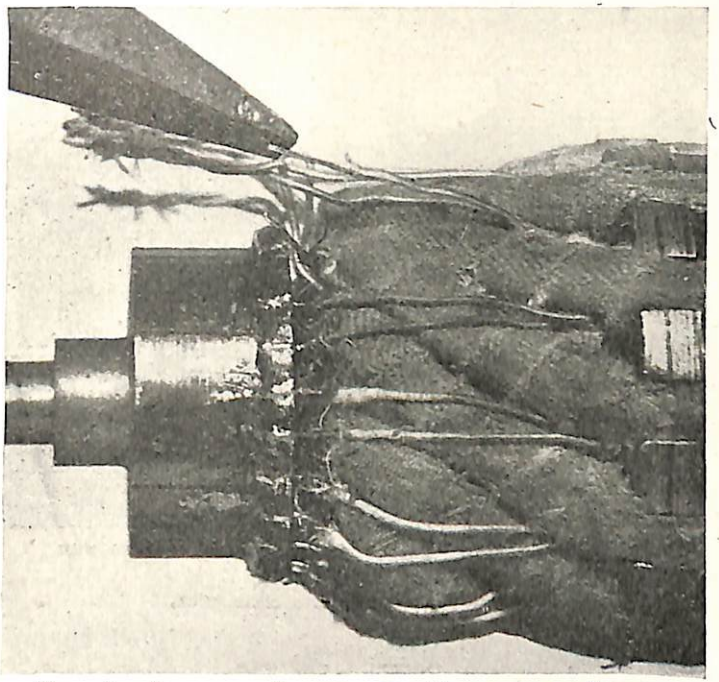


FIG. 18.—TINNING A LEAD BEFORE SOLDERING IN POSITION.

This ensures a sound joint. Do not use soldering spirits or paste for any of the soldering operations; use only resin or resin dissolved in methylated spirit.

were two, one slightly in advance of the other. The armature at the stage ready for soldering the connections to the commutator is shown in Fig. 17.

Each pair of connections are now soldered to their segments in turn, taking care to observe the same pitch in connecting as before. In the example illustrated, the leads are so arranged that they are soldered to the segments opposite to the points where they are brought out from the coils.

When the leads have been cut to length they are

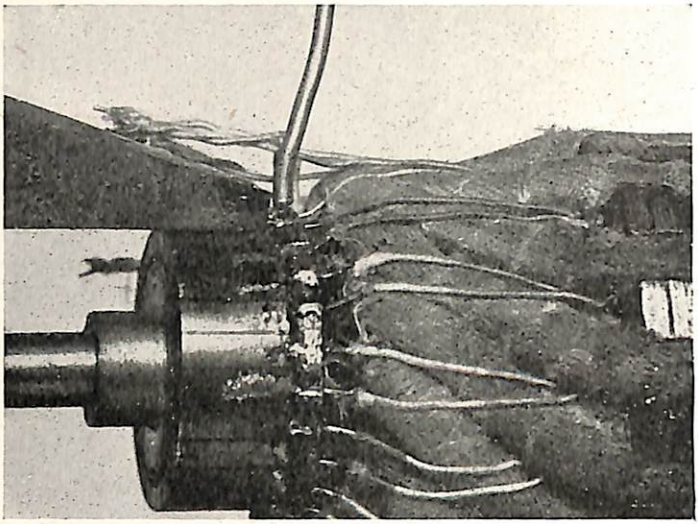


FIG. 19.—SOLDERING ONE OF THE CONNECTIONS TO THE COMMUTATOR.

Resin-cored solder gives a clean joint.

first tinned, as shown in Fig. 18. This ensures a perfect electrical joint. The slots in the commutator risers are already tinned from the previous winding. The ends are not twisted together but are put into the slots in the risers one on top of the other. The wire should fit tightly in the slots unless the gauge has been made smaller for a higher voltage. Where the armature is to be rewound with thicker wire for a lower voltage, it will be necessary to enlarge these slots before putting any wire on the armature.

Fig. 19 shows the operation of soldering the connections to the commutator. The narrow side of the bit should be used so as to heat up only one segment at a time, or the previous connections may be loosened,

besides taking an unnecessary amount of heat from the iron.

Do not attempt to solder the wires to the commutator with a soldering iron having a copper bit of less than one pound. If the job is attempted with a small soldering iron the copper bars of the commutator will conduct all the heat from the bit and cool it rapidly to a temperature below soldering heat. If, on first attempting to solder the connections to a commutator, the solder does not run properly, then either the bit is not hot enough or else the commutator is dirty. Make sure that the soldering iron is kept clean and properly tinned. Do not allow the iron to become overheated and avoid placing the iron in an open fire, rather heat it on a gas ring.

Finishing Off.

When the armature has been connected up, the end windings and the portions of the coils in the slots are bound with tinned copper or steel wire. Before the binding wire is put on, a layer of thin presspahn is wound round to protect the winding from the binders.

The binders are prevented from becoming loose by running the turns together with solder. As the binders are tinned wire there is no difficulty in making them solid with solder. After this the armature is, if necessary, varnished and baked. The moisture in the windings is first expelled by baking the armature as a whole for one or two hours according to size. It is very necessary to expel the moisture before impregnating the armature with insulating varnish or the moisture will be permanently imprisoned in the winding and thus cause low insulation. To drive out the moisture the baking temperature should be kept

between 200° and 220° Fahrenheit. A higher temperature is liable to char the insulation. Finally, the superfluous solder is turned off in a lathe and the commutator also turned and polished if necessary.

CHAPTER III

HOW TO REWIND A SMALL MOTOR

FOR THE SAME OR A DIFFERENT VOLTAGE

A Useful Winding Stand.

THE work of rewinding an armature is greatly facilitated if a stand is made to support the armature in the centres at the ends of the shaft, so that it can be easily rotated as the winding is put on. A simple and serviceable stand is made from two right-angled iron brackets screwed to a board. The uprights of the stand carry two pointed screws and lock-nuts on which the armature runs. Fig. 20 shows the stand with the finished armature mounted on it.

The brackets consist of a pair of ordinary cast shelf brackets 3 inches by $\frac{3}{4}$ inch. The top hole in the uprights is tapped out $\frac{1}{4}$-inch Whitworth. The centre screws are made from $\frac{1}{4}$-inch Whitworth set-screws by turning the ends to a point in a lathe to an angle of 60°. To accommodate several sizes of armatures the brackets may be set wider apart and the centre screws made 3 inches long.

STRIPPING THE ARMATURE

The armature selected is a vacuum-cleaner motor armature with semi-enclosed slots and twice as many

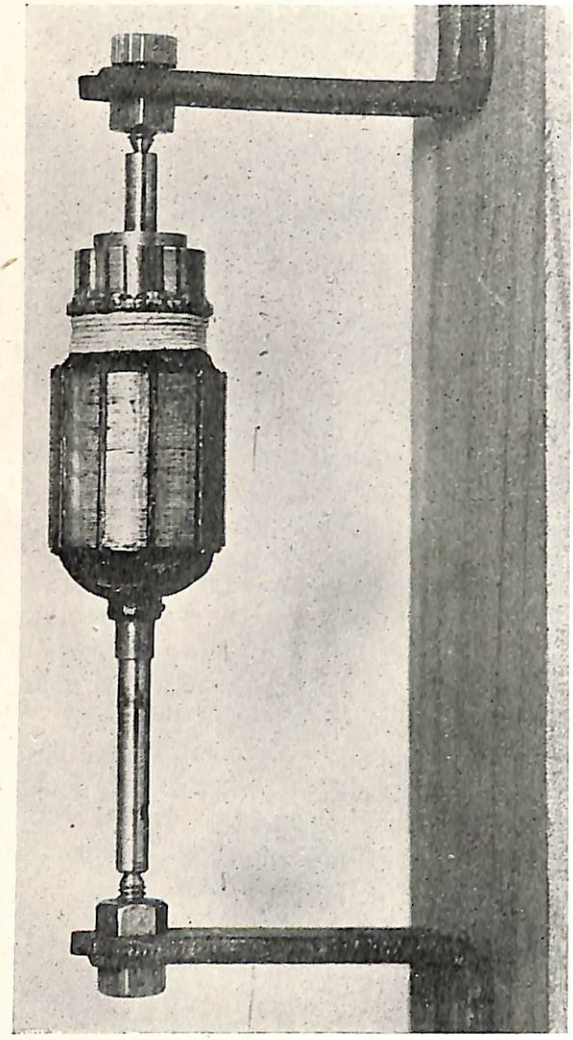


FIG. 20.—THE FINISHED ARMATURE ON THE REWINDING STAND.

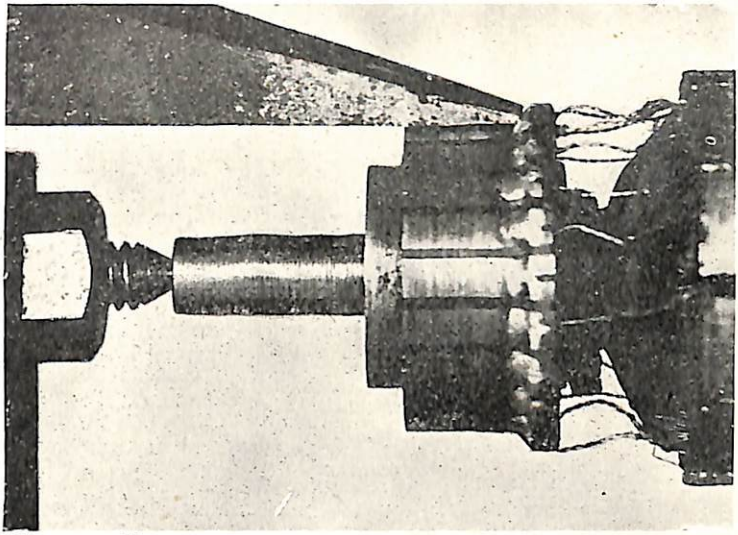


FIG. 21.—UNSOLDERING THE CONNECTIONS TO THE COMMUTATOR.

commutator segments as armature slots. Therefore there must be four coils in each slot.

First Remove the Binding.

The first step in stripping the core is to remove the binding from the commutator ends of the winding. This should be done carefully so as not to injure the connections to the commutator. Next remove the wedges or presspahn strips from the tops of the slots.

Examine the Armature Coils.

Examine the back of the winding and find the coil which was wound on last, then trace it to the commutator end and notice to which of the commutator bars this winding is connected. It is necessary to do this in order to obtain the pitch of the winding

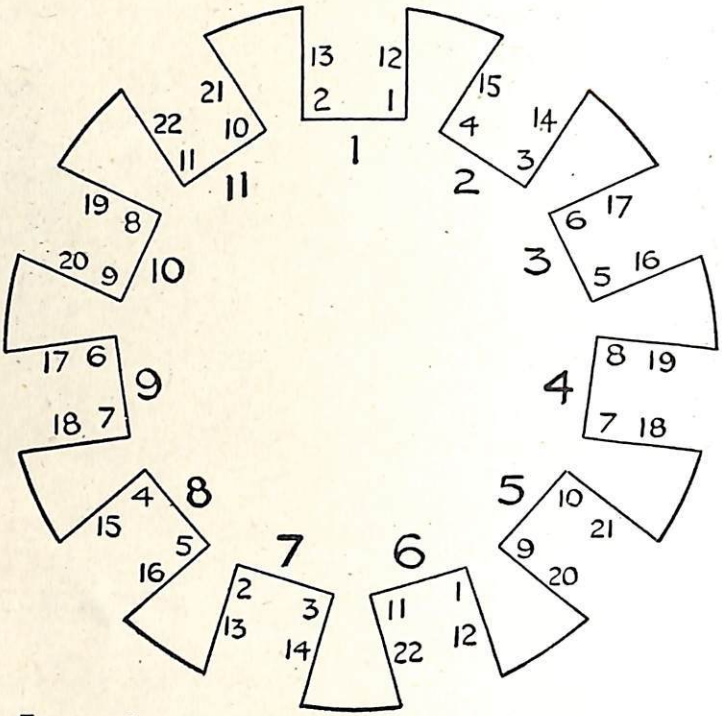


FIG. 22.—SHOWING THE ORDER OF WINDING THE COILS IN AN ELEVEN SLOT ARMATURE.

and also the angular relation between the coils and the commutator segments.

Make a Plan of the Winding.

Make a development plan of the armature and the commutator segments side by side, numbering the segments in each case. Put a scratch on the armature and call this No. 1 slot and do the same for the commutator. Now draw a diagram of the coil and its connections just traced out, which will appear as the

TABLE VII

TABLE OF COPPER CONDUCTORS

S.W.G	Diameter (Inches).	Sectional Area (Square Inches).	Current Capacity in Amperes per Square Inch.				
			2,000	3,000	4,000	5,000	6,000
12	0·104	0·00849	17	25	34	42	51
13	0·092	0·00665	13	20	27	33	40
14	0·080	0·00503	10	15	20	25	30
15	0·072	0·00407	8·1	12	16	20	24
16	0·064	0·00322	6·4	9·7	13	16	19
17	0·056	0·00246	4·9	7·4	10	12	15
18	0·048	0·00181	3·6	5·4	7·2	9·1	11
19	0·040	0·001256	2·5	3·8	5·0	6·3	7·5
20	0·036	0·001018	2·0	3·1	4·1	5·1	6·1
21	0·032	0·000804	1·6	2·4	3·2	4·0	4·8
22	0·028	0·000616	1·2	1·8	2·5	3·1	3·7
23	0·024	0·000452	0·90	1·4	1·8	2·2	2·7
24	0·022	0·000380	0·76	1·1	1·5	1·9	2·3
25	0·020	0·000314	0·63	0·94	1·3	1·6	1·9
26	0·018	0·000254	0·50	0·76	1·0	1·3	1·5
27	0·0164	0·000211	0·42	0·63	0·84	1·1	1·3
28	0·0148	0·000172	0·34	0·52	0·69	0·86	1·0
29	0·0136	0·000145	0·29	0·43	0·57	0·72	0·86
30	0·0124	0·000121	0·24	0·36	0·48	0·60	0·72
31	0·0116	0·000106	0·21	0·32	0·42	0·53	0·63
32	0·0108	0·0000916	0·18	0·27	0·37	0·46	0·55
33	0·0100	0·0000785	0·16	0·23	0·31	0·39	0·47
34	0·0092	0·0000665	0·13	0·20	0·27	0·33	0·40
35	0·0084	0·0000554	0·11	0·17	0·22	0·27	0·33
36	0·0076	0·0000454	0·090	0·14	0·18	0·23	0·27
37	0·0068	0·0000363	0·073	0·11	0·15	0·18	0·22
38	0·0060	0·0000283	0·057	0·085	0·11	0·14	0·17
39	0·0052	0·0000212	0·042	0·063	0·085	0·11	0·13
40	0·0048	0·0000181	0·036	0·054	0·072	0·090	0·11
41	0·0044	0·0000152	0·030	0·045	0·060	0·075	0·090
42	0·0040	0·0000126	0·025	0·038	0·050	0·063	0·076

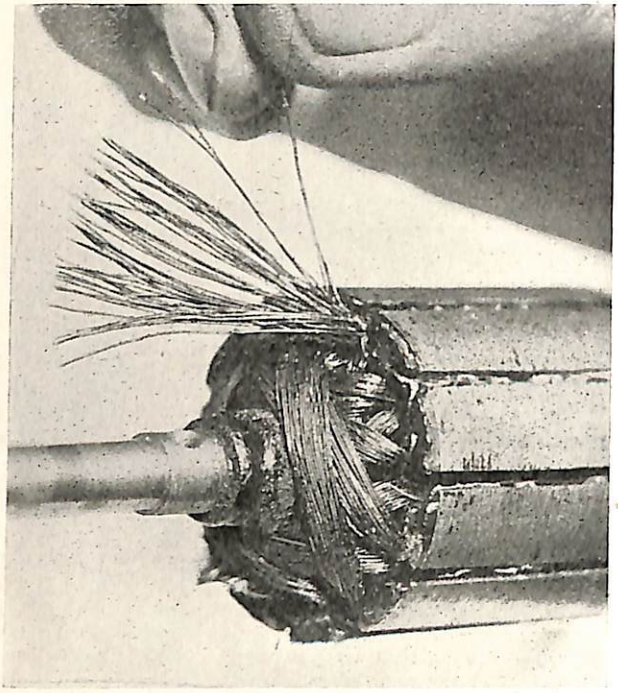


FIG. 23.—COUNTING THE TURNS PER COIL BEFORE REMOVING THE COILS FOR REWINDING.

lines A in Fig. 29. This gives the clue to the whole winding. Trace the path of the next coil in the same way and draw in on the development plan as lines B.

If each slot is dealt with in turn round the armature, this gives the complete winding diagram. The next thing to note is the order of winding the coils, for the slots must be wound in a particular order so as to obtain electrical and mechanical symmetry. The winding order is noted as the coils are removed one at a time.

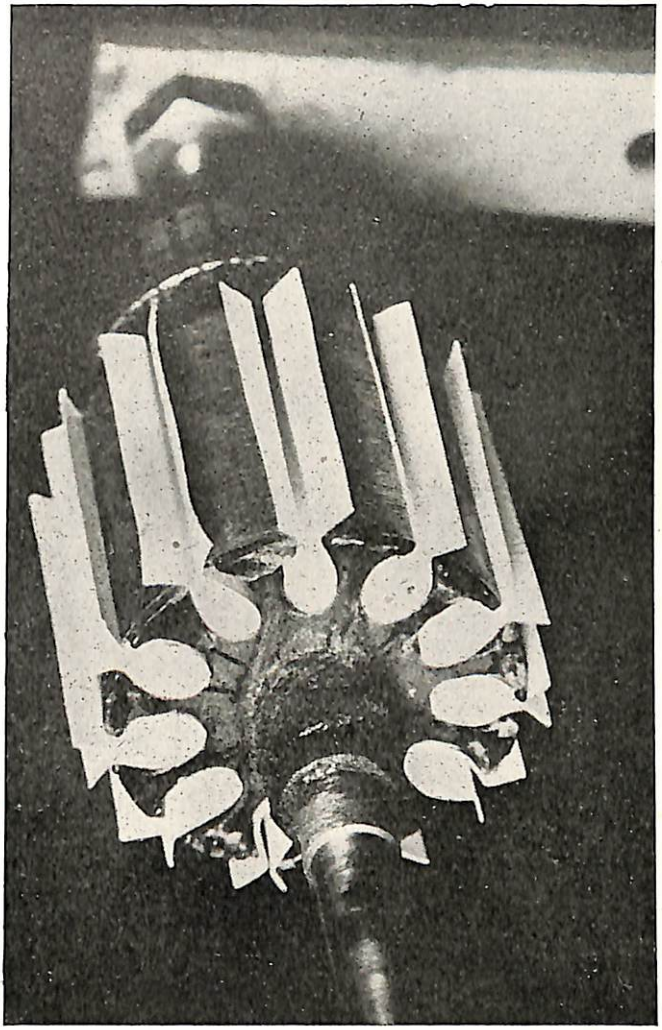


FIG. 24.—THE ARMATURE PREPARED WITH NEW SLOT INSULATION READY FOR REWINDING.

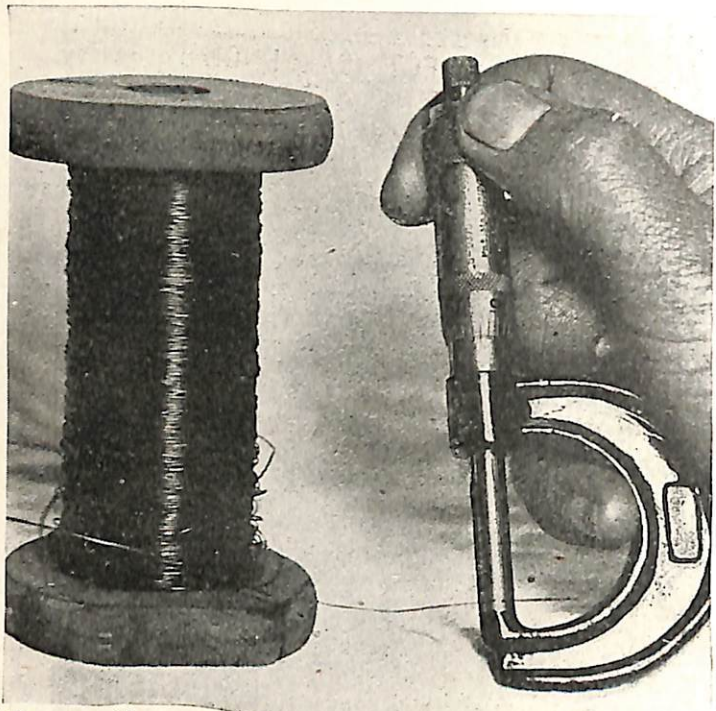


FIG. 25.—MEASURING THE SIZE OF THE WIRE WITH A MICROMETER. This shows 0·012 inch diameter or 28 S.W.G.

Removing the Coils.

Disconnect all the commutator connections with a soldering iron, Fig. 21, and cut through the last coil at the back end with pliers, and pull it through from the front. As it is a 22-section armature, this is coil No. 22 in order of winding. When this coil has been cut through count the number of turns before removing, as shown in Fig. 23. Each coil is removed in turn in this way, noting on the diagram at the same time

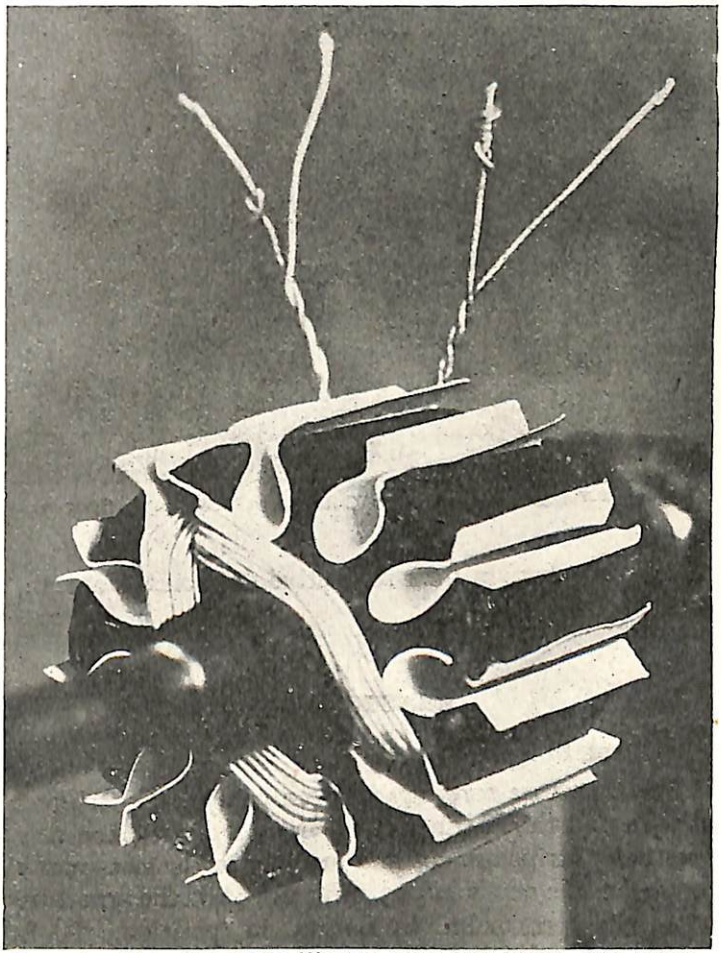


FIG. 26.—THE ARMATURE WOUND WITH THE FIRST TWO COILS.

Showing the ends temporarily twisted together and the starts of the windings knotted.

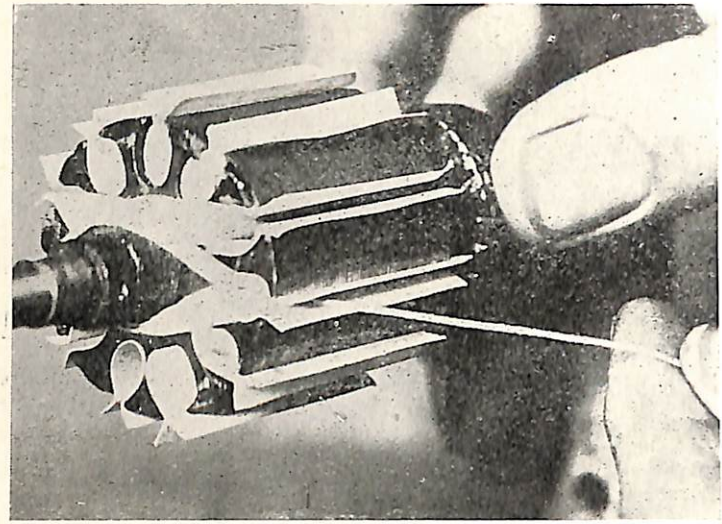


FIG. 27.—WINDING THE THIRD COIL FROM SLOT 2 TO SLOT 7.

the coil numbers in their respective slots on the sketch, as shown in Fig. 22.

REASSEMBLY

The First Stage.

The armature core having been completely stripped of wire and the old insulation from the slots, the new presspahn strips are cut and inserted in the slots ready to receive the new winding. Fig. 24 shows the armature with the presspahn insulation in position. It is necessary to cut the presspahn strips accurately. They should be exactly the length of the armature plus the thickness of the cheek insulation so that the armature slots are completely insulated.

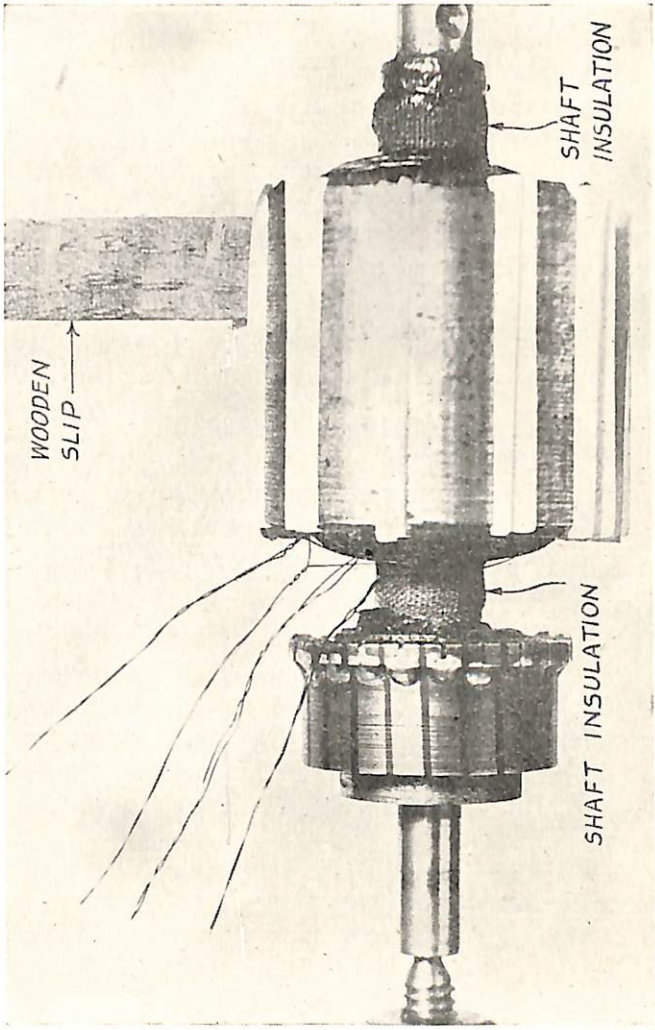


FIG. 28.—TO PREVENT THE WINDING SPREADING TOO MUCH A SLIP OF WOOD IS USED TO PRESS DOWN THE WINDING EVERY TEN TURNS.

Size of Wire for a Copy-wind.

If the machine is to work on the same voltage it is essential to use a wire of the same specification as before. Wires up to 36 S.W.G. can be measured with a wire gauge, but finer than this a micrometer is the only safe way (Fig. 25). Before measuring the wire, carefully remove the insulation and note whether the covering is silk or cotton and whether it is single or double. Use the same kind of wire for the repair. In this connection note that Universal motors are sometimes wound with resistance wire.

Winding for Different Voltage.

When the original winding data and working voltage are known it is a simple matter to calculate the size and quantity of wire for a different voltage. Suppose the armature had 23 turns per coil for 230 volts, then for 100 volts there would be 10 turns per coil. Thus the general case may be stated :

$$\frac{\text{Turns in original winding}}{\text{Turns in new winding}} = \frac{\text{Original voltage}}{\text{New voltage}}$$

As the different winding has to carry a heavier current for a lower voltage, and a lower current for a higher voltage, the size of the wire must also be different. As before, if the voltage is being reduced from 230 to 100, the new current will be $\frac{230}{100}$, or 2·3 times the former current, and the wire will be 2·3 times the area of the original wire.

$$\frac{\text{Sectional area of original winding}}{\text{Sectional area of new winding}} = \frac{\text{New voltage}}{\text{Original voltage}}$$

By referring to a table of properties of electrical conductors the suitable gauge is easily selected.

Suppose the armature were wound with 36 S.W.G. for 230 volts, then 31 S.W.G. is selected for 100 volts as this is the nearest available size.

Converting a Motor for a Higher Voltage.

It is not always possible to wind an armature for a higher voltage than was originally intended unless the commutator is suitable. Ten volts per commutator segment must be allowed, therefore, if the commutator has 22 segments, the armature may be wound for any voltage up to 220, but not more for safe commutation.

Winding the Coils.

The general rule for winding armatures of this type with an odd number of slots is to start at No. 1 slot, winding in two coils, each just less in span than the diameter of the armature as shown in Fig. 29 For example, this armature has eleven slots, therefore coils are wound round Nos. 1 and 6 slots and Nos. 1 and 7 slots. The next coils are then wound round Nos. 2 and 7, and 2 and 8. Fig. 27 shows winding the third coil. Every slot is then wound with two coils, if the commutator has twice the number of segments as the armature. The slot winding will then be according to the table on page 56.

As the turns are wound on they must be counted as it is very important to have the coils electrically equal and not just to quarter-fill the slot with wire for each coil. Armatures of this type are best wound with double silk-covered wire, although if the original wire had a thinner covering, that is single silk-covered or enamelled, the latter must be used or the correct amount of wire will not be accommodated.

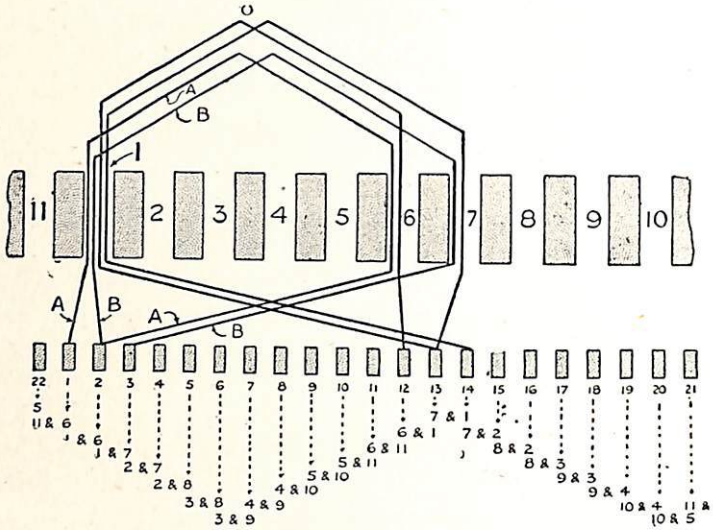


FIG. 29.—DEVELOPMENT PLAN OF AN ELEVEN-SLOT ARMATURE WITH A TWENTY-TWO SEGMENT COMMUTATOR.

Showing the connections of the four coils wound in No. 1 slot. Below the plan of the commutator the figures represent the coils (numbered according to the slots in which they are wound) to which the respective segments are connected. By reading horizontally the connections to any particular coil can be picked out.

WINDING TABLE

Wind round slots	1	and	6	Wind round slots	6	and	1
then	1	,,	7	then	7	,,	1
,,	2	,,	7	,,	7	,,	2
,,	2	,,	8	,,	8	,,	2
,,	3	,,	8	,,	8	,,	3
,,	3	,,	9	,,	9	,,	3
,,	4	,,	9	,,	9	,,	4
,,	4	,,	10	,,	10	,,	4
,,	5	,,	10	,,	10	,,	5
,,	5	,,	11	,,	11	,,	5
,,	6	,,	11	,,	11	,,	6

How to Keep the Coil Ends Distinct.

Extreme care must be taken when winding not to chafe the insulation of the wire on the edges of the armature, as one short-circuited turn is sufficient to prevent the machine working properly. As the coils are wound, their respective ends are temporarily twisted together, as shown in Fig. 26, and as a precaution they are labelled 1, 2, 3, 4, and so on, to facilitate connecting up to the commutator. As the origin of the ends is difficult to trace when the armature is completely wound, it is necessary to distinguish between the start and finish of each coil. This is done by tying a knot in the starting end of each coil, Fig. 26, taking care to wind all the coils in the same direction.

Do Not Omit This.

As each ten turns are wound on, the winding is gently pressed down in the slots with a thin wooden slip, as shown in Fig. 28. The ends of the windings, or those portions between the ends of the slots, are pressed up to the cheek in the same way.

Connecting to the Commutator.

If the foregoing plan has been followed, there is no difficulty in sorting out the ends or connecting up, because the commencement of each winding is knotted and each pair of wires is labelled. Untwist each pair of ends in turn and connect the finish of No. 1 coil to the start of No. 2 coil and the finish of No. 2 coil to the start of No. 3 coil, and so on, alternately, until the ends are connected up as the coils are wound.

Before Soldering.

Cut the ends so that they are just long enough to come through the slots in the commutator risers. Now clean all the ends for about $\frac{3}{8}$ inch, twist them securely and solder them together. The wires are now bent back carefully over the armature and the commutator ends of the winding are bound with linen tape. At the same time any space between the commutator and the winding is filled up so that an even surface is formed on which to bind the ends of the winding.

Soldering the Commutator.

The armature connections are now soldered to the commutator. It is necessary to use a big soldering iron and to heat up the bar properly to make sure of a strong connection. When these connections have been made the projecting ends of the armature slot insulation are tucked into the slots and pressed down.

Finishing Off.

The next step is to bind the connecting wires so that they will not become dislodged when the machine is running. For a small armature of this type it is sufficient to wind over the ends with thin string in a single layer. Before binding the ends, take the string over the top of each slot in a zig-zag fashion to retain the winding.

To Ensure Good Insulation.

Bake to expel moisture, then immerse in insulating varnish and allow to soak for at least half an hour. One of the baking varnishes, such as "Armacel,"

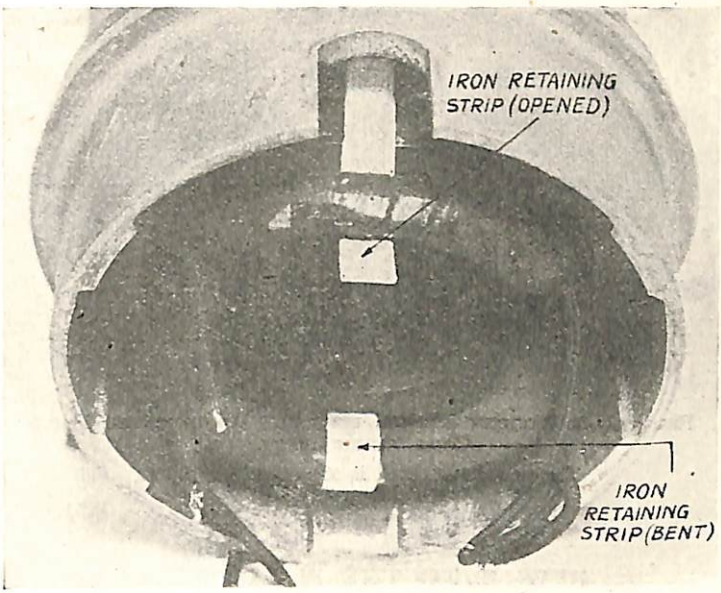


FIG. 30.—A TYPICAL METHOD OF SECURING THE FIELD COILS TO THE POLE PIECES OF SMALL MOTORS.

To remove a coil it is only necessary to flatten the strip and pull it out.

specially prepared for the purpose, is best for this. When the armature has been impregnated and allowed to dry it is baked for two hours at 200° F., taking care that the windings do not touch any part of the oven.

The Final Touches.

When the armature is cool it is put in a lathe and the shaft and commutator cleaned of varnish with fine glasspaper. If the commutator is out of truth or badly worn it may now be trued up and any superfluous solder removed from the commutator should there be any likely to foul the brushes.

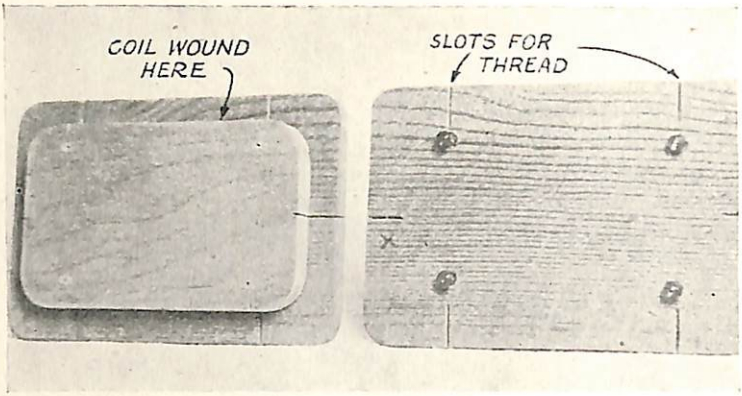


FIG. 31.—A WOODEN FORMER USED FOR WINDING THE FIELD COILS TAKEN APART.
The removable cheek is shown on the right.

REWINDING THE FIELD COILS

Whereas the armatures of most small motors designed to run in bi-polar fields have to be wound by hand, the field coils are former wound. Consequently, rewinding the field coils presents less difficulty than the armature.

Removing the Old Winding.

The field coils of small universal motors, in which the field magnets are laminated, are retained in position by an iron strip which passes over the top of the pole-pieces and under the ends of the coil. Fig. 30 shows how these strips are arranged. To remove a field coil it is necessary to straighten out the ends of a strip and pull it out when the coil may be removed intact from the pole-piece.

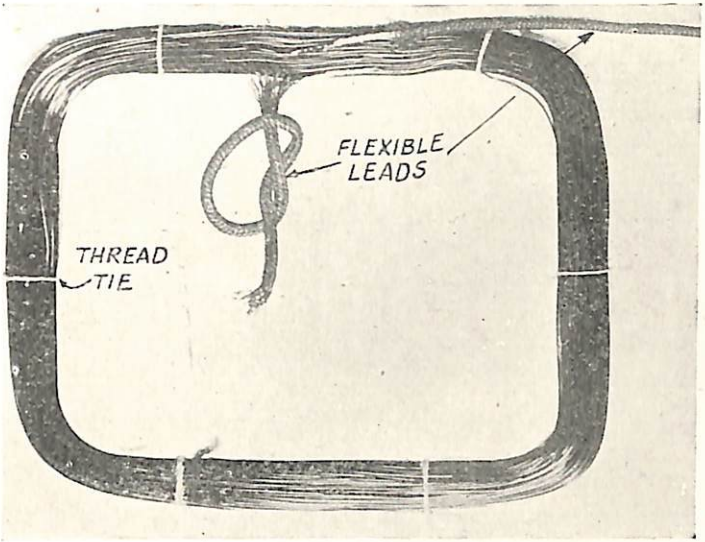


FIG. 32.—A PARTLY-FINISHED COIL.

Showing the method of tying the wire and the flexible leads soldered on. The thread is removed as the coil is taped up.

A Copy Wind.

When the defective coil has been removed carefully note how the conductors are insulated. It is a common practice, in a good-class motor, for the coils to be bound with empire tape, with a layer of cotton tape on top, which is varnished. Make a note also of the relation to the two connections so as to avoid difficulty when reassembling the windings. After removing the tape from the winding, tie up one side of the coil with thread, to prevent the turns splaying out, then count the number of turns and measure the size of the wire. The remaining sides of the coil are then tied with thread. Next flatten out the coil to obtain a size for making the former.

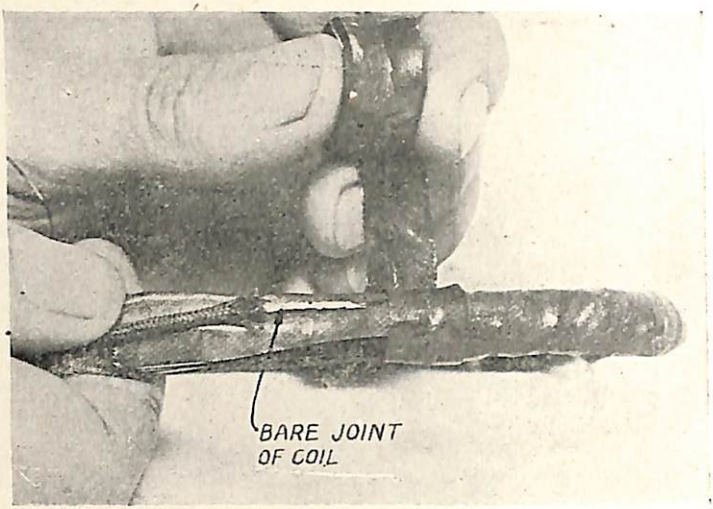


FIG. 33.—BINDING THE COIL WITH EMPIRE TAPE.

This shows how the bare joint of the coil to the flexible lead is insulated from the winding. The cotton braiding is slipped back over the bare joint before binding it in.

Making the Former.

A wooden former, on which the field coils are wound, is shown in Fig. 31. It consists of a centre-piece made to fit inside the old coil when flat, and of the same thickness as the coil itself. The fixed and removable cheeks of the bobbin are made of $\frac{1}{2}$-inch wood and are made large enough to give a margin round the bobbin centre, sufficient to contain the winding. With the bobbin assembled several saw cuts are made round the edge so that the coil may be tied up before removing. The saw cuts are taken $\frac{1}{8}$ inch below the winding surface to enable the thread to be passed under the coil after winding. After making the saw cuts, smooth off the inside winding faces and round off the inside edges of the cheeks. The centre-piece of the bobbin

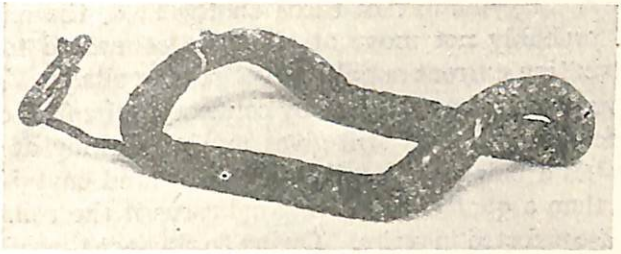


FIG. 34.—THE FINISHED COIL READY FOR FIXING ON THE FIELD MAGNET.

is tapered off towards the removable cheek to facilitate the removal of the coil after winding.

Winding for Different Voltage.

If the machine is being wound for a different voltage the field coils as well as the armature must be altered. The same rules apply to the modification of the field as for the armature. That is to say, the number of turns is proportional to the voltage and the area of the wire with which they are wound is inversely proportional to the voltage. This applies for series-wound motors as well as shunt-wound machines. If the voltage is being halved, the field coils need not be rewound; they are simply connected in parallel.

Rewinding for Alternating Current.

A motor may be rewound to work on alternating current if it has previously worked on direct current only if the field magnet system is laminated. Also the machine will run only as a series motor. It may not be necessary to rewind a small series motor when the supply is changed from direct to alternating. A trial will soon decide. If the machine is a slow-speed type

with a large number of turns on the field, the motor will probably not move at all when connected to an alternating current supply of the same voltage. This may generally be overcome by connecting the field coils in parallel. If this still gives much sparking at the brushes a pair of new coils must be wound containing less than a quarter of the original turns if the coils are to be connected in series. Owing to the fact that alternating current series commutator-motors must have a weak field for satisfactory operation, they cannot be wound to run at low speeds as can direct current types. In any case, the windings of a series-wound alternating-current motor are largely a matter of experiment.

Winding the Coils.

The coils are most conveniently wound by holding a cheek of the bobbin in an independent chuck in the lathe to which a counter may be attached. The coil must be wound slowly and as evenly as possible. The bobbin must run truly or the wire will catch on the rim of the bobbin cheeks. When the correct number of turns of wire have been put on, the bobbin is removed from the lathe, and pieces of thread used to tie up the winding temporarily. The removable cheek of the bobbin is then unscrewed and the coil carefully pulled from the former by means of the free ends of the thread. Short pieces of flex are then soldered to the ends of the winding. The coil is then as shown in Fig. 32.

Taping the Coils.

The next operation is to bind the coils with empire tape, if they are wound with enamel-covered wire. If cotton-covered wire is used, the coils are bound with

cotton tape and heated for half an hour in an oven to drive out the moisture. They are then thoroughly soaked in insulating varnish, baked and bent to shape while hot.

As the coils are taped up the flexible ends are brought out at convenient places. The bare joint of the wire to the flex is protected from the coil by laying a strip of tape under the connection and binding it in as shown in Fig. 33. The cotton braiding of the flex is slipped back over the bare joint to give an added protection. Give more overlap to the tape at the corners so that the binding does not part when the coil is bent.

Bending the Coils.

The coils may be bent in the fingers roughly to shape and finally shaped in position on the pole pieces. The finished coil is shown in Fig. 34. The coil is secured by the iron strips previously mentioned, as shown in Fig. 30. A piece of varnished paper or presspahn is put between the securing strip and the coil, so that the sharp edges of the metal do not injure the coil insulation.

CHAPTER IV

HOW TO MAKE A $\frac{1}{16}$-H.P. UNIVERSAL MOTOR

THE motor described in the chapter is chosen as being suitable for driving a small fan, grinding-wheel, sewing-machine or for working a number of models. The maximum output is $\frac{1}{16}$ h.p. The various parts can be constructed by anyone possessing a 3-inch lathe, which is essential for making the commutator, turning the end-frames and the armature shaft.

The motor is designed so that it may, with suitable windings, be driven from any voltage, either A.C. or D.C.

The list of components and materials from which they are made are given herewith.

The Armature Spindle.

The main part of the work of making a motor is in the construction of the armature. The first stage of making the armature is turning the spindle. This is made from $\frac{3}{8}$-inch. diameter bright mild steel.

Cut off a length of this size steel $5\frac{7}{8}$ inches long, face the ends and centre each truly with a Slocomb centring drill so that when finished the rod is then $5\frac{13}{16}$ inches long as shown in the working drawing, Fig. 36. The exact dimension of the overall length may, of course, be varied to suit different methods of drive. The

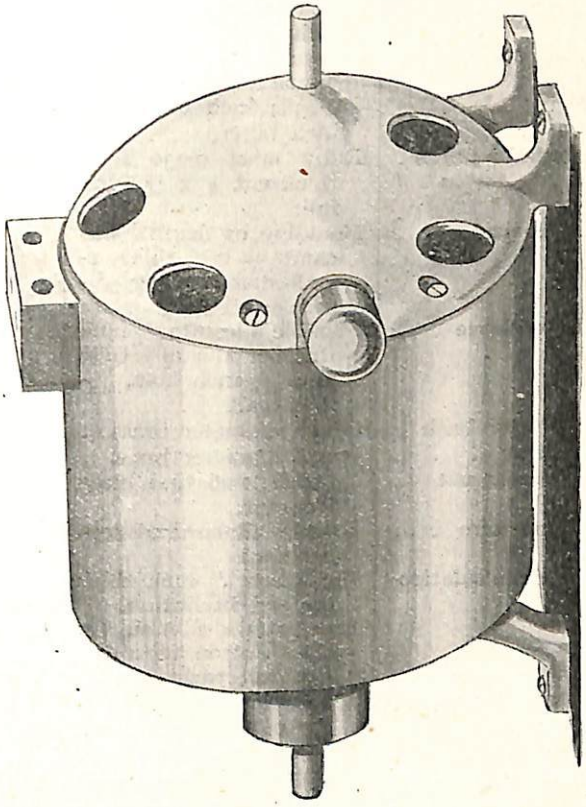


FIG. 35.—THE FINISHED $\frac{1}{16}$-H.P. MOTOR, THE MAKING OF WHICH IS DESCRIBED IN THIS CHAPTER.

COMPONENTS REQUIRED

Component.	Material.	Quantity.
Armature spindle .	$\frac{3}{8}$-inch diameter bright mild steel.	1
Armature stampings	$1\frac{1}{2}$-inch diameter Stalloy stampings with 11 semi-closed slots, $\frac{5}{16}$-inch hole for spindle.	100
Armature clamping nut.	$\frac{5}{16}$ inch × 26 t.p.i. steel locknut.	1
Bearings	$\frac{3}{4}$-inch diameter by $\frac{1}{4}$ × $\frac{1}{4}$ inch ball races.	2
Commutator bars .	Drawn copper segments $\frac{5}{8}$ inch long by $\frac{11}{32}$ inch, 0·1364 inch to 0·0389 inch taper.	22
Commutator micas .	Ruby mica 0·030 inch thick cut $\frac{5}{8}$ × $\frac{11}{32}$ inch full.	22
Micanite washers .	Moulding or flexible micanite $\frac{1}{32}$ inch thick, 1-inch diameter by $\frac{7}{16}$-inch wall.	2
Micanite sleeve . .	Flexible micanite $\frac{1}{32}$ inch thick or micanite tube with $\frac{7}{16}$-inch hole, $\frac{1}{32}$-inch wall.	1
Commutator bush .	$\frac{3}{4}$-inch diameter brass .	1
Clamp ring . . .	$\frac{3}{4}$-inch diameter brass .	1
Commutator nut .	$\frac{7}{16}$ inch × 26 t.p.i brass lock-nut.	1
Armature wire . .	Double silk-covered copper wire.	3 oz.
Armature insulation	Presspahn $\frac{1}{32}$ inch thick for end insulation.	2, $1\frac{5}{8}$-inch circles.
	Presspahn 0·2 mm. for slots Cotton tape and Armacel varnish.	12 inches × $1\frac{5}{8}$ inches.
Field magnet . .	2 pole stampings in Stalloy 0·018 thick.	90
Field coils . . .	Enamel covered wire .	4 oz.
Field coil insulation	Empire tape $\frac{3}{8}$ inch wide	3 yards
End frames . . .	Cast aluminium . . .	2
Field frame . . .	Metal tube or casting .	1
Brushes	Carbon, $\frac{3}{16}$ inch square, $\frac{1}{2}$ inch long.	2

lengths given allow for a wide pulley or worm at one end and for a narrow V-pulley at the commutator end.

After centring the bar, it is mounted between centres in a lathe and the short $\frac{1}{4}$-inch shoulder is turned first. The diameter of this part should be made so that the ball race is a good push fit on it. The same applies to the other end of the shaft. The $\frac{3}{4}$-inch long shoulder $\frac{5}{16}$-inch diameter is the next operation. This part of the shaft takes the commutator.

When these two shoulders have been turned the shaft is reversed and the two long shoulders turned. It will be necessary to use a travelling steady for this. Set up the steady before starting to turn, because once the shaft becomes tapered it will be found difficult to correct it. The long $\frac{5}{16}$-inch diameter shoulder should be turned so that the armature stampings slide on easily but without shake. Finally, screw cut the 26 per inch thread for the nut which is to clamp the stampings together.

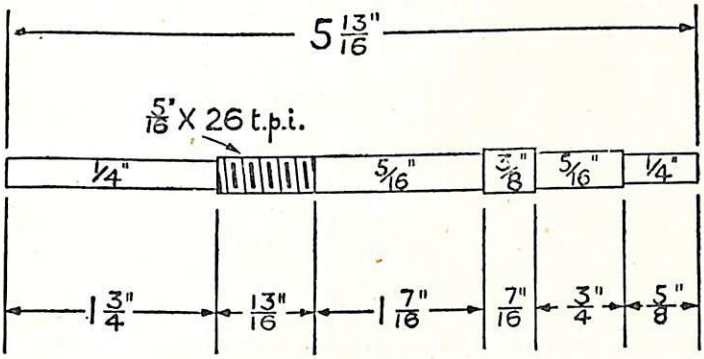


FIG. 36.—WORKING DRAWING OF THE ARMATURE SPINDLE WHICH IS TURNED FROM $\frac{3}{8}$-IN. DIAMETER BRIGHT MILD STEEL.

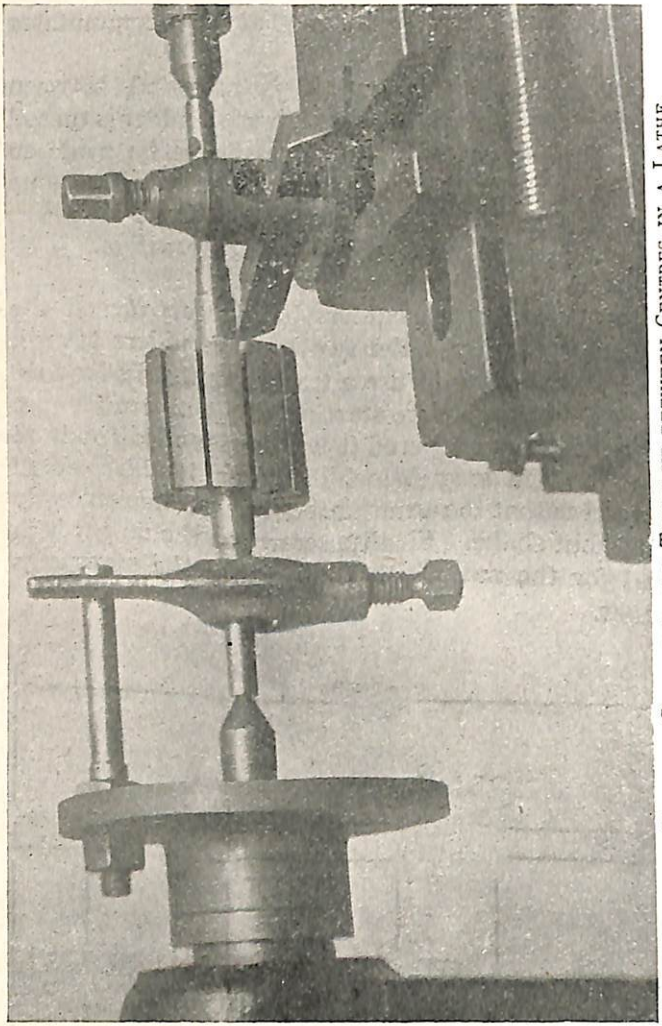


FIG. 37.—HOW THE STAMPINGS ARE TRUED-UP BETWEEN CENTRES IN A LATHE.
This is done after the stampings have been assembled on the armature spindle.

Assembling the Stampings.

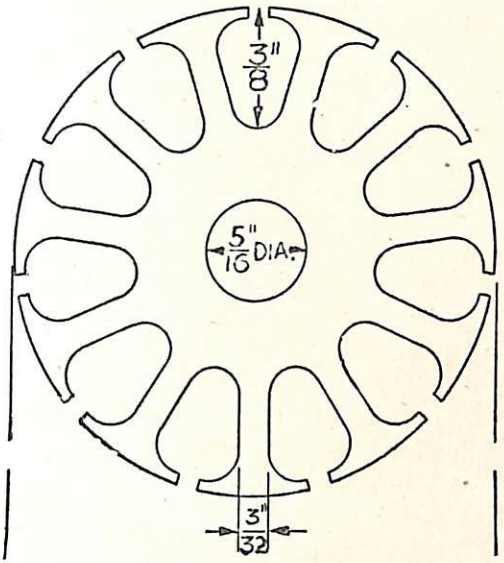


FIG. 38.—DIMENSIONS OF ARMATURE STAMPINGS.

The armature core is composed of about 96 of these stampings (1½ in. diameter) clamped together on the armature spindle. Some makes of stampings have a nick at the base of one slot. The nicks are lined up when the stampings are assembled to ensure perfect alignment of the stampings.

Before mounting the stampings on the shaft a special clamping nut is prepared. This may be turned from a standard $\frac{5}{16}$-inch 26 nut, which is a cycle size. In order that it shall not unduly enlarge the winding at this end of the armature the nut is turned $\frac{1}{8}$ inch thick and filed down to fit a $\frac{1}{4}$-inch spanner. Chamfer the nut well. The stampings are now threaded on to the spindle; 96 should be sufficient to make 1½ inches. It will be noticed that the armature stampings are covered with very thin paper on one side. Keep all the papered faces the same way round so as to insulate each stamping from its neighbour. Discard any rusty or bent stampings, also any which may have an extra thickness of paper.

When the required number of stampings have been

threaded on the spindle, the nut is put on and the stampings lightly clamped. A piece of iron strip is then used to line up the stampings and hold them in alignment while the nut is done up as tightly as possible. For this purpose the commutator end of the spindle is held in the vice, taking care not to bruise or bend the shaft. Larger stampings have a key-way punched in the hole so that the stampings may be keyed to the shaft. For a small motor, however, a clamping nut is sufficient to prevent the rotation of the stampings on the shaft.

The shape and dimensions of the stampings are shown in Fig. 38.

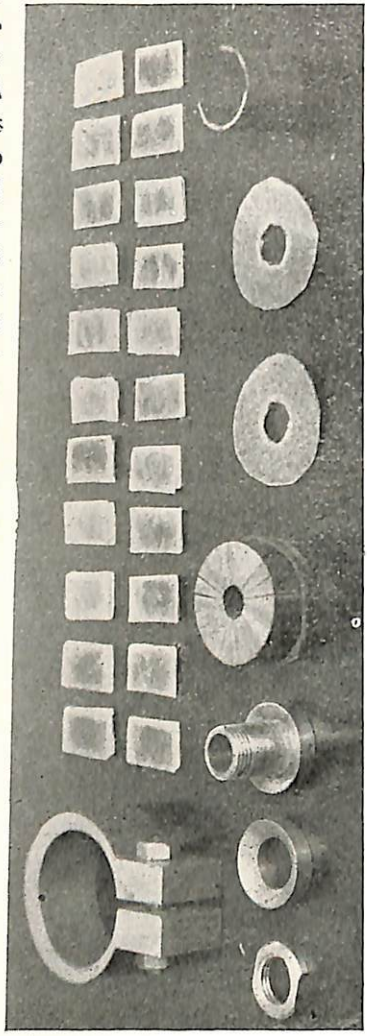


FIG. 39.—THE VARIOUS COMPONENTS OF THE COMMUTATOR.
Showing also the clamp which is used to make it.

Truing-up the Armature.

It often happens that the clamping up of the stampings distorts the slender shaft, or, if the shaft is not bent the stampings do not run truly when the armature is spun on the lathe centres. If the shaft is bent it may be straightened by resting the two $\frac{1}{4}$-inch sections of the armature on a pair of V-blocks and tapping with a mallet or hammer and a piece of wood. It is not advisable to straighten the armature whilst it is mounted between centre, or the centres of the spindle may be damaged. These must be taken care of because they will be required for finishing the commutator and its subsequent returning from time to time. When the spindle runs true again the stampings are carefully skimmed up with a keen tool as shown in Fig. 37.

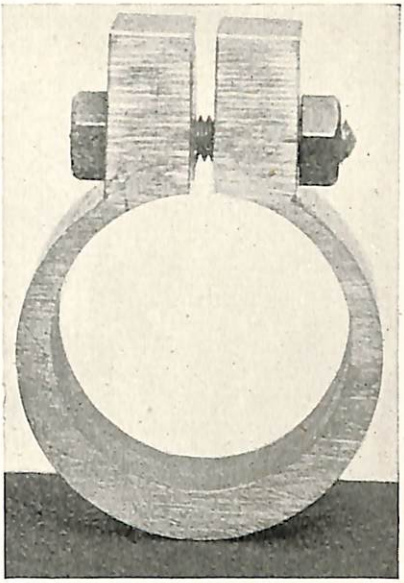


FIG. 40.—CLAMP RING FOR HOLDING THE SEGMENTS AND THE MICA TOGETHER.

This is used while the coned recesses are turned at each end of the commutator.

HOW TO MAKE THE COMMUTATOR

The various parts of the commutator together with the clamp which is used to make it are shown in Fig. 39.

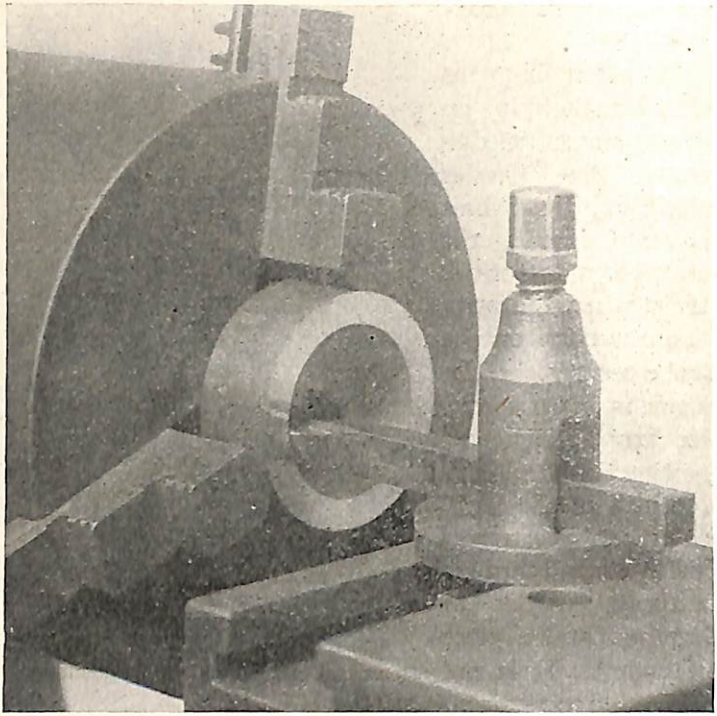


FIG. 41.—THE FIRST STAGE IN MAKING THE CLAMP RING.
This is to bore out the brass tube to $1\frac{3}{16}$ inch diameter.

The Clamp.

Before the commutator can be started it is necessary to make a special clamp ring to hold the segments and their micas while the turning on them is done. The finished clamp is shown in Fig. 40. It is made from $\frac{5}{8}$ inch of brass tube about $\frac{3}{16}$-inch to $\frac{1}{4}$-inch wall. Unless a piece of tube is obtainable $1\frac{3}{16}$-inch inside diameter, the tube is first bored out to this size as shown in Fig. 41. The ring thus bored to size is then mounted

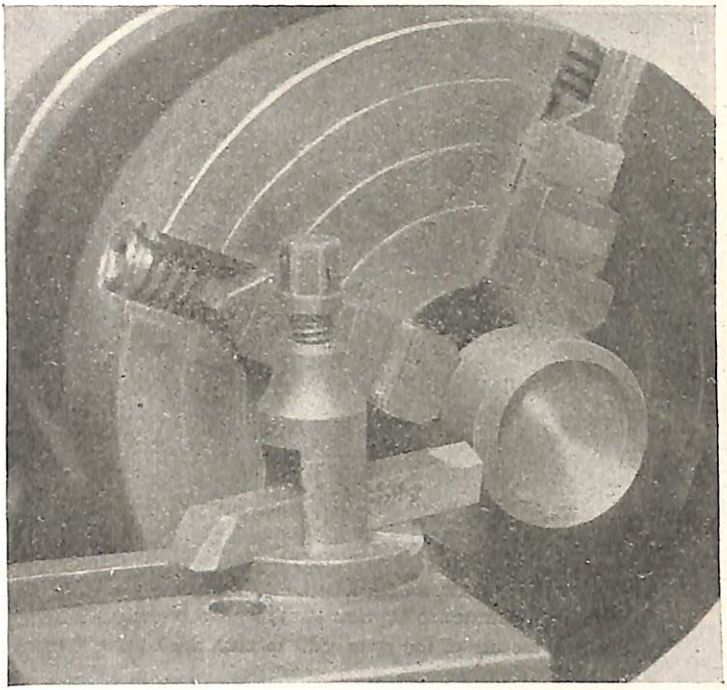


FIG. 42.—THE SECOND OPERATION IN MAKING THE CLAMP RING.
Showing how to turn the outside eccentric with the bore.

on an eccentric mandrel held in an independent chuck as shown in Fig. 42. This produces an eccentric ring. The object of making the ring eccentric is to ensure the clamping of all the segments properly, which a concentric ring does not do. After turning the eccentric ring a brass block is brazed or silver-soldered central with the thin side of the ring. Before splitting the ring a hole is drilled for a 2 B.A. steel screw. One half of the block may be tapped instead of using the nut, which gives more room for holding the ring in

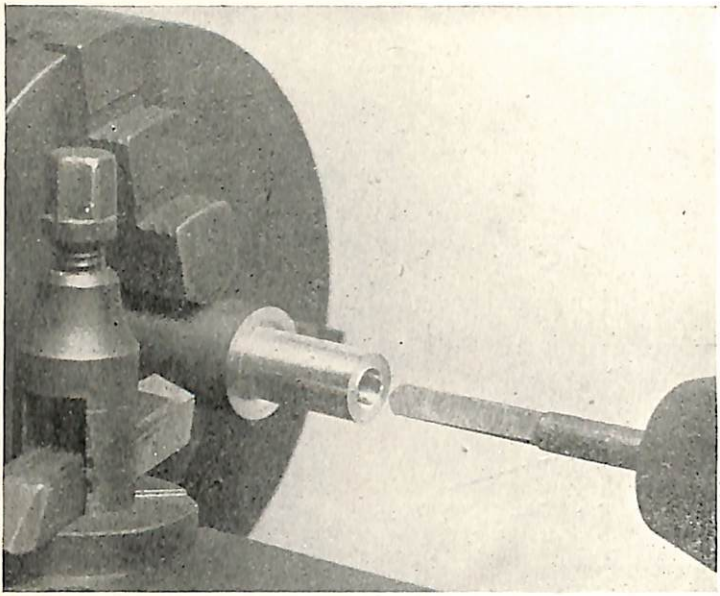


FIG. 43.—MAKING THE COMMUTATOR BUSH (1).
Showing the use of the spear drill to bore the hole.

the chuck for subsequent operations. The slot is then cut out about $\frac{5}{32}$ inch wide. Two hacksaw blades put together will do this operation.

The Commutator Bush.

Four stages in making the foundation bush of the commutator are shown in Figs. 43 to 46. A piece of $\frac{3}{4}$-inch brass rod is held in a self-centring chuck and a shoulder turned 1 inch long and $\frac{7}{16}$-inch diameter. Next centre the faced end of the rod carefully and drill out with a spear drill, to a depth of $1\frac{3}{16}$ inch. A spear drill as shown in Fig. 43 should be used for the first drilling because this type of drill is less liable to run

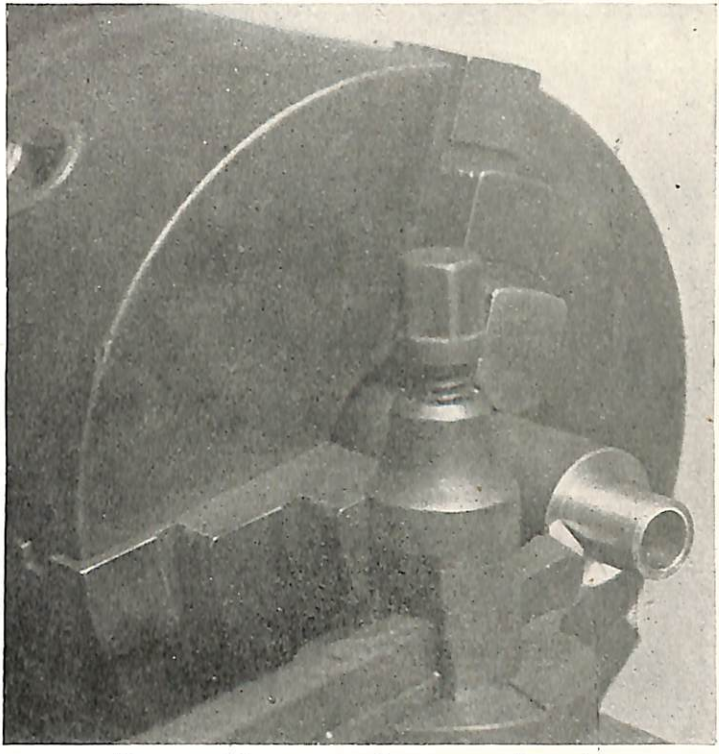


FIG. 44.—MAKING THE COMMUTATOR BUSH (2).

This shows the second operation, which consists of recessing the shoulder at an angle of 60° to the turn of the bush. The exact angle is not important provided that the angle of the commutator cones is made the same. The motor described in this chapter can be constructed by anyone possessing a 3-inch lathe which is essential for making the commutator, turning the end-frames and the armature shaft. The making of the commutator requires more patience and care than the other parts.

out of centre than a twist drill. The hole is finished to size with a $\frac{5}{16}$-inch reamer or a carefully ground drill of the same size, so that the bush will push on the armature spindle without shake. Fig. 44 shows the next operation. This is recessing the shoulder at an

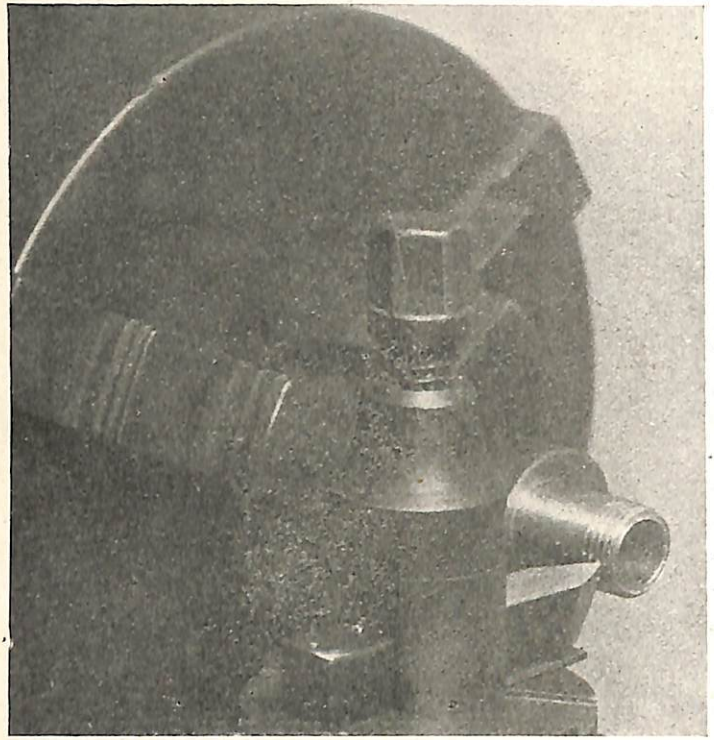


FIG. 45.—MAKING THE COMMUTATOR BUSH (3).

Showing how to cut the thread on the commutator bush. Reference should also be made to Fig. 51 which shows the completed commutator in section. The commutator bush will be clearly seen with the threaded portion on the right. A brass nut is screwed on to this end of the bush when the assembly is complete.

angle of 60° to the turn of the bush. The exact angle is not important, provided that the angle of the commutator cones is made the same.

After turning the coned recess, the thread is cut as shown in Fig. 45. The pitch of the thread is the same as for the armature spindle ; that is, 26 per inch. The

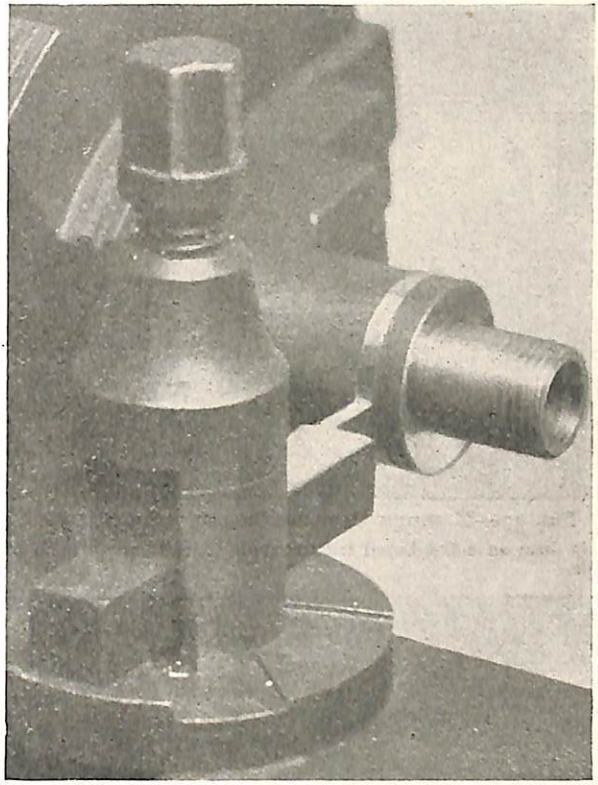


FIG. 46.—MAKING THE COMMUTATOR BUSH (4).

The final operation in making the commutator bush, showing the use of a parting tool.

thread is cut longer than necessary for which purpose will be seen when finally assembling the commutator. Lastly, the bush is parted off to leave $\frac{5}{32}$-inch long head, as shown in Fig. 46.

The Clamping Ring.

The clamping ring is made next because it is turned from the same size of metal as the bush. Its shape is

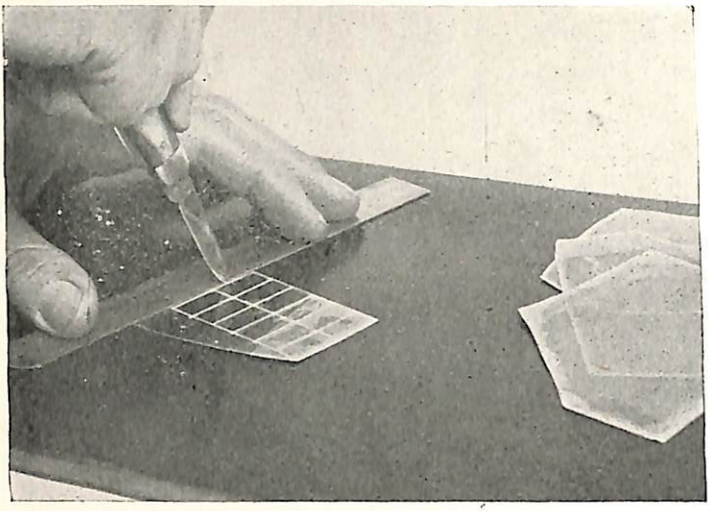


FIG. 47.—MARKING OUT THE COMMUTATOR MICAS.

This is done on a flat board with the aid of a sharp penknife and a steel rule.

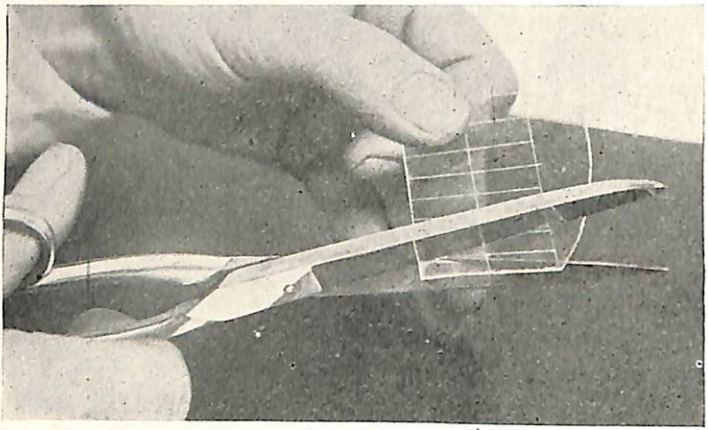


FIG. 48.—CUTTING UP THE COMMUTATOR MICAS WITH A PAIR OF SCISSORS.

If any of the small pieces should flake up, keep each rectangle separate so that the uniform thickness is preserved.

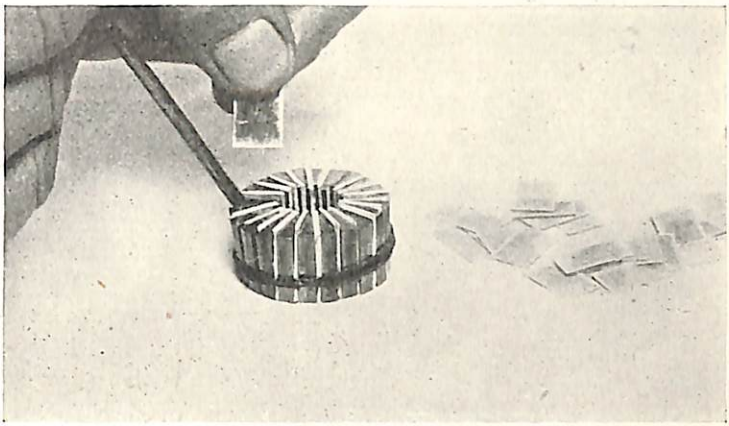


FIG. 49.—ASSEMBLING THE COPPER SEGMENTS IN THE MICA PREPARATORY TO TURNING.

Elastic bands are used to hold the assembly together while the micas are being inserted. Check the thicknesses of the micas carefully with a micrometer in order to ensure their uniformity.

similar to the head of the commutator bush. A $\frac{7}{16}$-inch hole is drilled in the $\frac{3}{4}$-inch bar $\frac{1}{4}$ inch deep, and a coned recess turned as for the head of the bush. The ring is then parted off $\frac{5}{32}$-inch overall thickness.

A nut is then made $\frac{1}{8}$-inch thick from $\frac{5}{8}$-inch brass bar to fit the thread of the bush. Two flats filed on this are sufficient.

The Commutator Micas.

The mica material is supplied in irregularly shaped pieces which are shown in Fig. 47. The correct thickness is 0·030 inch. The thickness may be made up of any number of pieces or by splitting up a thicker piece. The mica is easily split up with a knife into uniform leaves within a thousandth part of an inch. When the required thickness has been made up in sufficient quantity to cut 22 pieces $\frac{5}{8} \times \frac{11}{32}$ inch full,

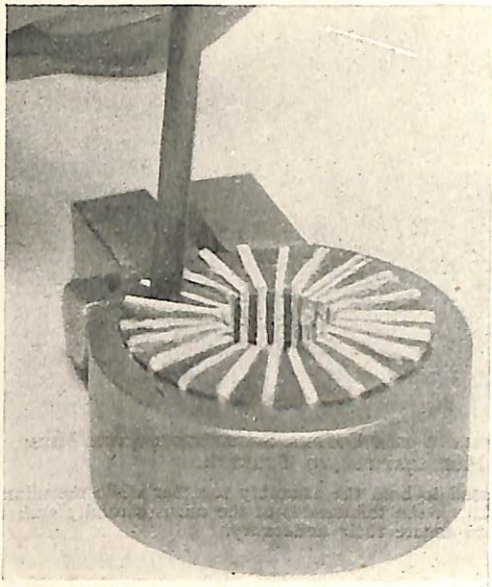


FIG. 50.—LEVELLING UP THE MICAS IN THE COPPER SEGMENTS.

This is done after the clamp has been pushed over them and the elastic bands removed.

the mica is laid on a flat board and the rectangles marked out with a penknife as shown in Fig. 47. The pieces are then cut up with a pair of sharp scissors or metal snips. See Fig. 48. Owing to the incohesion of the lamina structure of the mica, these small pieces will flake into thinner leaves when cut. This does not matter so long as each portion is preserved separately so as to give a uniform thickness of 0·030 inch to each piece. There is no harm in, say, cutting up twice the number of pieces 0·015 inch thickness and making up the thickness in this way.

The Copper Segments.

Although the copper segments can be made by one skilled with a file, it is better to purchase the copper section drawn to the size shown in the preceding table. Each section is cut $\frac{5}{8}$ inch long. Preparatory to assem-

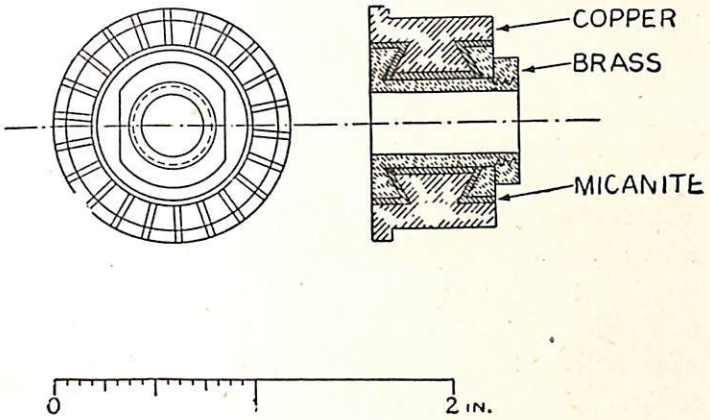


FIG. 51.—END ELEVATION AND SECTION OF THE FINISHED COMMUTATOR.
This is drawn to scale to show the finished sizes of the various parts.

bling the copper and mica for turning, the burrs are taken off the faces of the copper bars by rubbing on a sheet of fine sandpaper. The burrs are also removed from the large end of the taper. This ensures that the segments bed closely. Keep the faces of the copper flat, for if the edges are rounded a gap may be formed in the finished commutator which assists the formation of a dangerous burr when turning.

Assembling the Segments and Mica.

The twenty-two copper segments are now conveniently held together with elastic bands so that the coppers are easily parted with a pointer in order to insert the micas. This operation is shown in Fig. 49. Before inserting the micas check the thicknesses with a micrometer to ensure their uniformity. With the

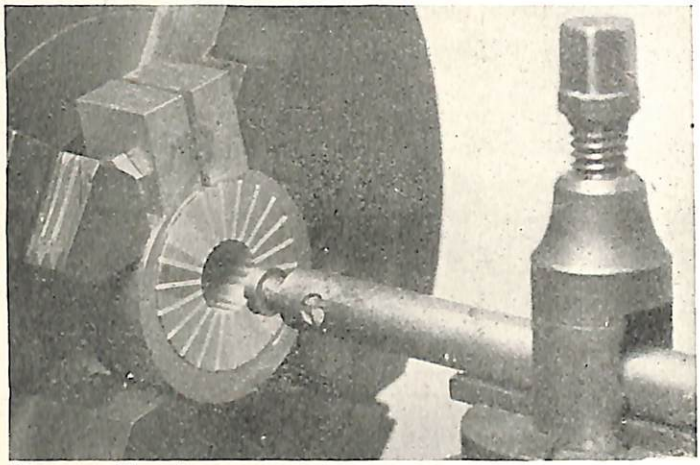


FIG. 52.—THE COMMUTATOR SET UP IN AN INDEPENDENT CHUCK FOR BORING AND FACING.

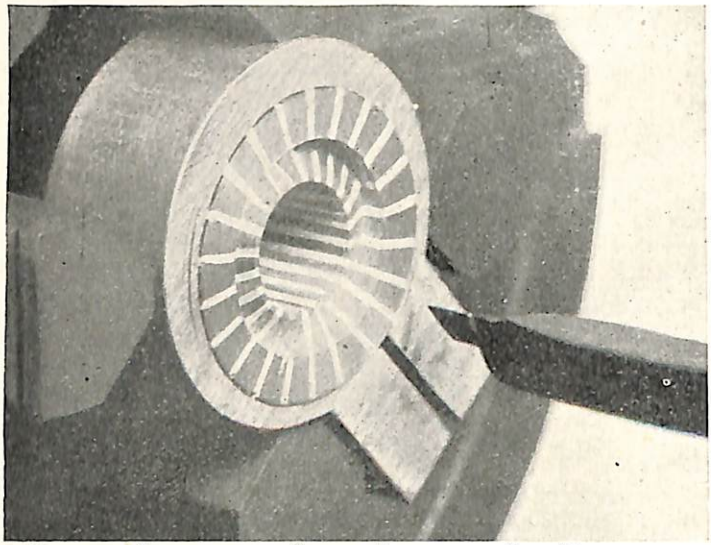


FIG. 53.—TURNING THE CONED RECESS AT ONE END OF THE COMMUTATOR.

When this end is finished the clamp is reversed in the chuck and the other end treated in a similar way.

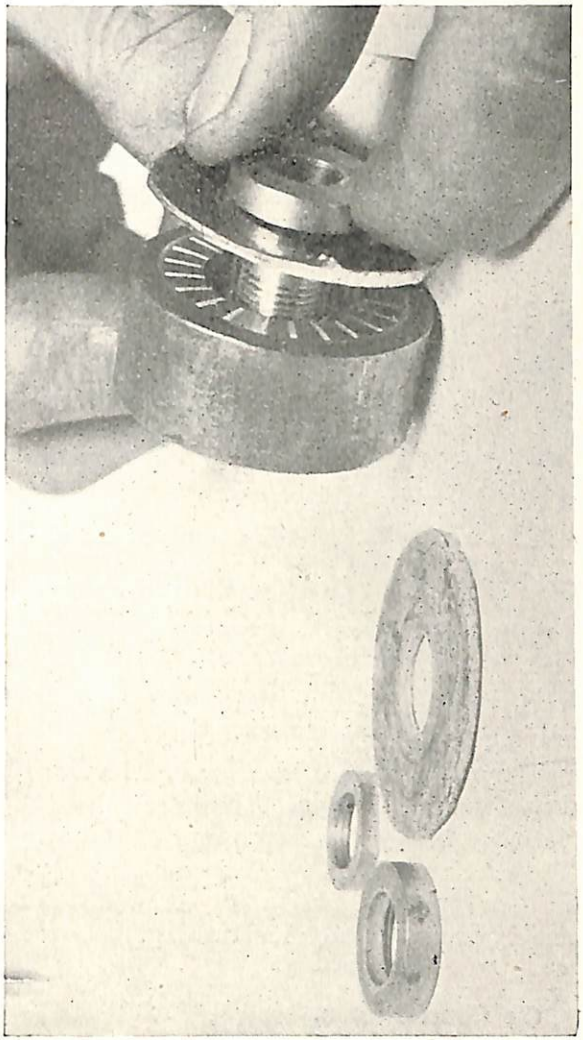


FIG. 54.—THE FINAL ASSEMBLY OF THE COMMUTATOR, FIRST STAGE.

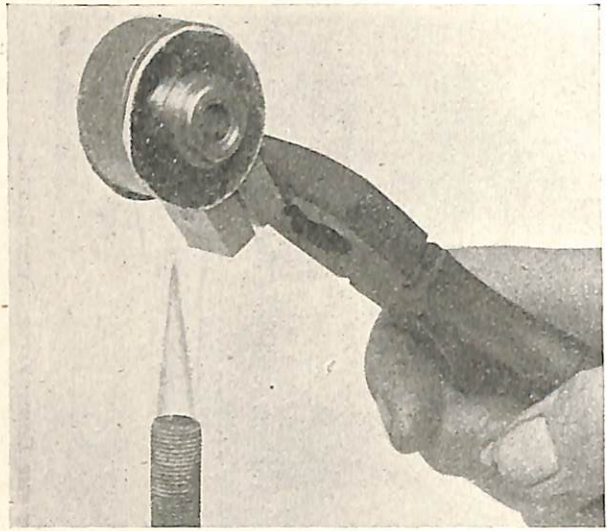


FIG. 55.—FINAL ASSEMBLY OF THE COMMUTATOR, SECOND STAGE.

When the bush and micanite washers have been lightly clamped up, the whole assembly is heated over a gas flame until the micanite is soft enough to be formed into the coned recesses.

twenty-two pairs of micas and copper segments thus assembled the clamp is pushed on.

The copper segments are now pushed level with a thin rod as shown in Fig. 50. The micas should now project into the bore and at each end of the commutator. See that each segment is covered properly with mica and then tighten the clamping screw of the ring. The assembly is now ready for turning.

Turning the Commutator.

For the purpose of turning the commutator, it is held in an independent chuck as shown in Fig. 52.

The work is centred so that the bore of the clamping ring runs truly. The first step is to face one end of the segments and bore out the hole to $\frac{1}{2}$-inch diameter. Fig. 52 shows a boring bar in use for this operation. The turning tools must be kept sharp and the metal and mica must be removed in light cuts or the copper will tend to bridge over the surface of the mica edges. It will be found necessary to touch up the tool every two or three cuts to produce the best result, because mica soon takes the keenness from the tools, whether they are high-speed or ordinary carbon steel.

The next step is to turn the coned recess at one end of the commutator. This is shown in Fig. 53. Care must be taken when working into the corner that the tool does not chatter or dig. Before the coned part is turned the commutator end is recessed $\frac{1}{8}$ inch with a square shoulder. The diameter of the recess is $\frac{3}{16}$ inch, that is $\frac{3}{4}$ inch for the head of the bush, plus $\frac{1}{32}$ inch each side for the micanite insulation. When this part has been turned the commutator is reversed in the chuck and carefully centred so that the bore runs truly on its entire length, when a similar recess is turned at the other end of the commutator. The angle of the coned recesses must fit that of the bush and the clamping ring. The dimensions of the commutator are given in Fig. 51, which shows a section of the finished commutator drawn to scale. When the second end of the commutator has been recessed and faced, examine the edges of the micas to see whether any of them are partly or wholly bridged with copper. If the mica edges are quite clean the work is then removed from the chuck, but the clamp must not be released yet on any account.

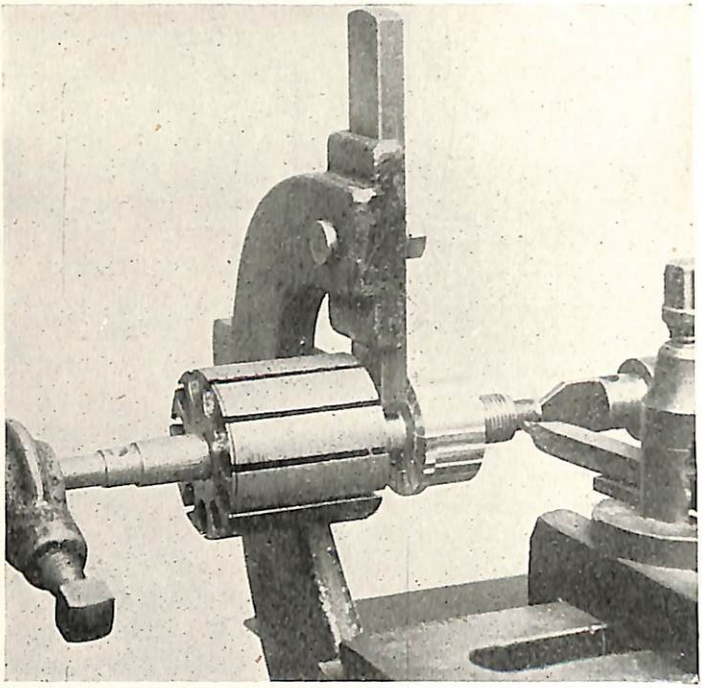


FIG. 56.—THE ARMATURE SET UP IN A LATHE FOR FINISHING THE COMMUTATOR.

A steady must be used to prevent chattering when turning the outside diameter. The superfluous thread at the end of the commutator is turned off while the armature is thus set up.

The Micanite Bush.

The micanite bush serves to insulate the commutator from the brass foundation bush. It may be cut from a piece of tube $\frac{1}{2}$-inch outside diameter and $\frac{7}{16}$-inch bore. The length of the bush is $\frac{7}{16}$ inch. Alternatively, the bush may be bent up from a piece of flexible micanite. To do this a piece of $\frac{1}{32}$-inch flexible micanite is cut $1\frac{9}{16} \times \frac{7}{16}$ inches, and bent while hot

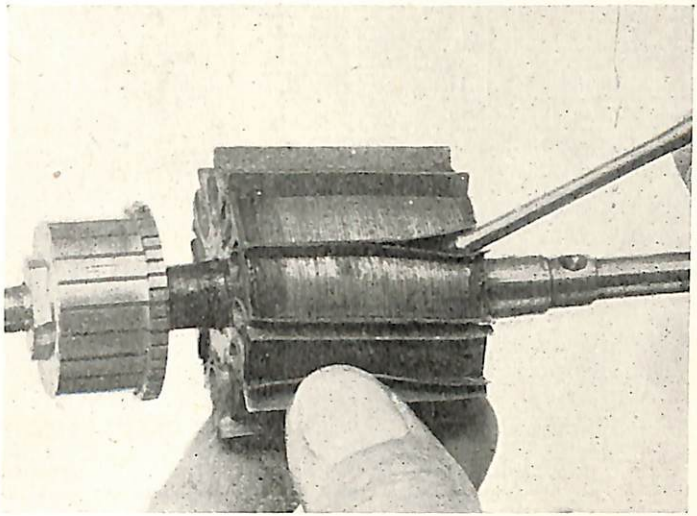


FIG. 57.—TURNING BACK THE EDGES OF THE PRESSPAHN SLOT INSULATION.
This is done so as to form a guide-in for the wire during winding.

round a warmed rod of $\frac{5}{16}$-inch diameter, so that the edges just meet when the split sleeve is closed firmly round the forming rod.

Assembling the Commutator.

The final assembly of the commutator is shown in Fig. 54. After lining the commutator hole with the micanite sleeve, one of the micanite washers is threaded on the bush which is then inserted into the bore of the commutator as shown. The other micanite washer is then pushed on the projecting thread and the clamping ring put on with its coned side facing the segments. The nut is then screwed on and done up finger tight.

The whole assembly is now held in a pair of pliers

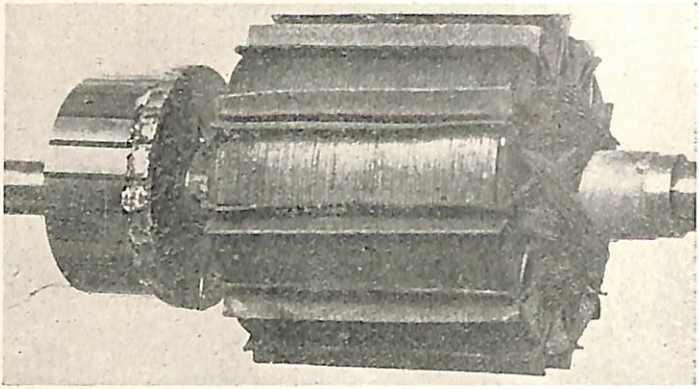


FIG. 58.—THE ARMATURE WITH HALF THE COILS WOUND AND CONNECTED TO THE COMMUTATOR.

At this stage the leads from the coils are insulated with cotton tape so that they do not come in contact with the second half of the winding.

over a flame to soften the micanite. This is shown in Fig. 55. As soon as the micanite becomes pliable, the nut is tightened with a spanner. The job is then reheated and the nut further tightened until the micanite washers are completely formed into the cones, and the nut is clamped as tightly as the thread will permit. The final tightening of the nut must be done while the job is hot or the micanite will not bed firmly on the cones and the commutator bars will not be securely held. The superfluous micanite is then cut off both sides and the commutator removed from the clamp.

Testing the Commutator.

The insulation between the segments is tested by means of a lamp bulb and the light mains. The full pressure of the mains is applied to each pair of

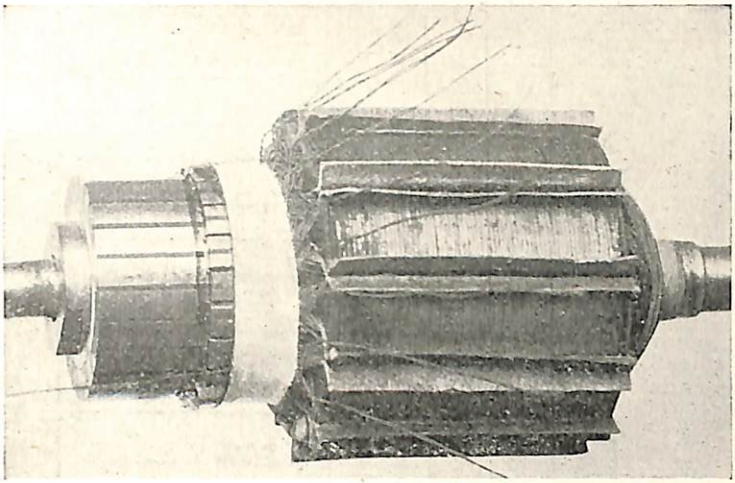


FIG. 59.—THE ARMATURE WINDING FINISHED WITH THE SECOND HALF OF THE CONNECTIONS READY FOR SOLDERING TO THE COMMUTATOR.

adjacent segments, with a bulb in series. The bulb will light up if any two segments are bridged anywhere. Also test between each segment and the bush. The most likely cause of failure is the imperfect forming of the micanite cones, which may not have covered the metal cones properly in the assembling process.

Mounting the Commutator.

There are two methods of securing the commutator to the armature shaft. First, the bore of the commutator bush may be made a force fit on the shaft, but unless the sizes are just right the commutator may be damaged while being pressed on, or the commutator may work loose and damage the connections. A simpler and equally effective way of mounting a small

TABLE VIII

TABLE SHOWING ARMATURE AND FIELD WINDINGS FOR DIFFERENT VOLTAGES, BOTH A.C. AND D.C.

Volts.	A.C. Series 40/60 Cycles.				D.C. Series.				D.C. Shunt.			
	Armature.		Field.		Armature.		Field.		Armature.		Field.	
	S.W.G. D.S.C.	Turns per Coil.	S.W.G. Enam.	Turns per Coil.	S.W.G. D.S.C.	Turns per Coil.	S.W.G. Enam.	Turns per Coil.	S.W.G. D.S.C.	Turns per Coil.	S.W.G. Enam.	Turns per Coil.
100	35	35	26	167	35	35	26	214	35	40	38	2,860
110	35	37	27	185	35	37	27	237	36	47	39	3,960
120	36	40	27	200	36	40	27	260	36	47	39	3,960
200	38	67	30	330	38	67	30	430	39	74	41	5,275
210	38	70	30	350	38	70	30	450	39	74	41	5,275
220	38	73	30	370	38	73	30	475	40	95	42	6,200
230	38	75	31	384	38	75	31	495	40	95	42	6,200
240	38	75	31	400	38	75	31	515	41	107	43	7,400
250	38	75	32	415	38	75	32	535	41	107	43	7,400

commutator is to solder it to the armature shaft. This is done by tinning the short $\frac{5}{16}$-inch section of the shaft and the inside of the commutator bush, and, while both are still hot the commutator is pushed right up to the shoulder on the shaft. Take care not to overheat the commutator, but make the shaft rather hotter than is necessary to melt the solder so that should the bush be too cool when pushed on, the extra heat may be supplied by the shaft.

Finishing the Commutator.

By mounting the commutator on the shaft before turning up the outside diameter the need for making a special mandrel for this purpose is obviated. The first operation in truing-up the outside is to face the back and turn off any superfluous solder on the part of the shaft between the commutator and the stampings. The front face is then trued if necessary and then the outside diameter is turned parallel, so as to leave it as large as possible. This is now the diameter of the risers or the narrow extensions of the segments which house the armature connections. After this the commutator is turned down so as to leave the risers $\frac{1}{16}$ inch higher and $\frac{3}{32}$ inch long. The diameter of the working part of the commutator is now $1\frac{1}{16}$ inch.

Fig. 56 shows the armature set up between centres in a lathe for the finishing of the commutator. In order to prevent chattering due to the slender nature of the shaft it is necessary to use a steady as shown. The illustration shows the superfluous thread of the bush being turned off after the commutator has been finished. The thread is faced off flush with the clamping nut as shown in the sectional drawing. See Fig. 51.

Although the initial turning of the commutator may

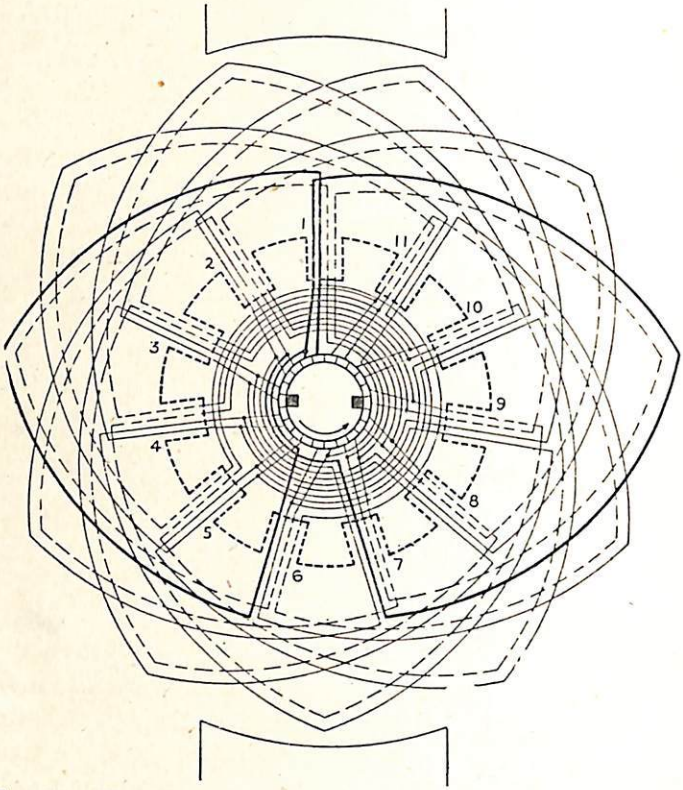


FIG. 60.—THE COMPLETE ARMATURE WINDING DIAGRAM FOR THE 11-SLOT ARMATURE WITH 22 COMMUTATOR SEGMENTS.

One pair of coils is shown by heavy lines. The whole winding consists of 11 such pairs of coils wound from each of the 11 slots in order. The position of the brushes is indicated by two shaded squares inside the commutator. The second half of the winding, which starts from No. 6 slot, is indicated by dotted lines. The inter-connections of the coils are indicated by circular dots. The connections to the commutator have a lead to suit the direction of rotation shown.

have been done accurately, do not be mystified if the commutator is found to run out of true with the bore after it has been assembled. This is due to the unequal flow of the micanite when forming up the cones.

Riser Slits.

Each riser must now be slotted to receive the armature wires. This may be done with a circular saw about $\frac{3}{4}$-inch diameter mounted on a mandrel in the lathe. The armature is clamped at the correct height on the saddle and turned round for each of the twenty-two cuts. The slits are cut almost the full depth of the risers, taking care not to injure the commutating surface. The thickness of the saw should be the nearest available size larger than the gauge of wire to be used for winding the armature. If the commutator is turned on a mandrel before mounting it on the armature shaft, the slits may be cut with a fine hand saw or metal fretsaw.

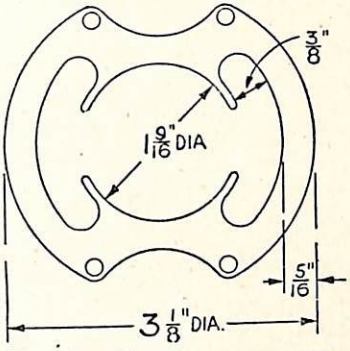


FIG. 61.—THE DIMENSIONS OF THE FIELD MAGNET STAMPINGS.

Some makes of stampings have two flats instead of the circular recesses on the outer diameter. Both types are suitable.

WINDING THE ARMATURE

Shaft Insulation.

The end-windings of a hand-wound armature must necessarily be in close proximity to a short section of the shaft beyond each end of the stampings. It is thus essential to insulate that portion of the shaft between the back of the commutator and the armature and about $\frac{1}{2}$-inch of the shaft at the back of the armature. The material used is empire tape which is stuck with

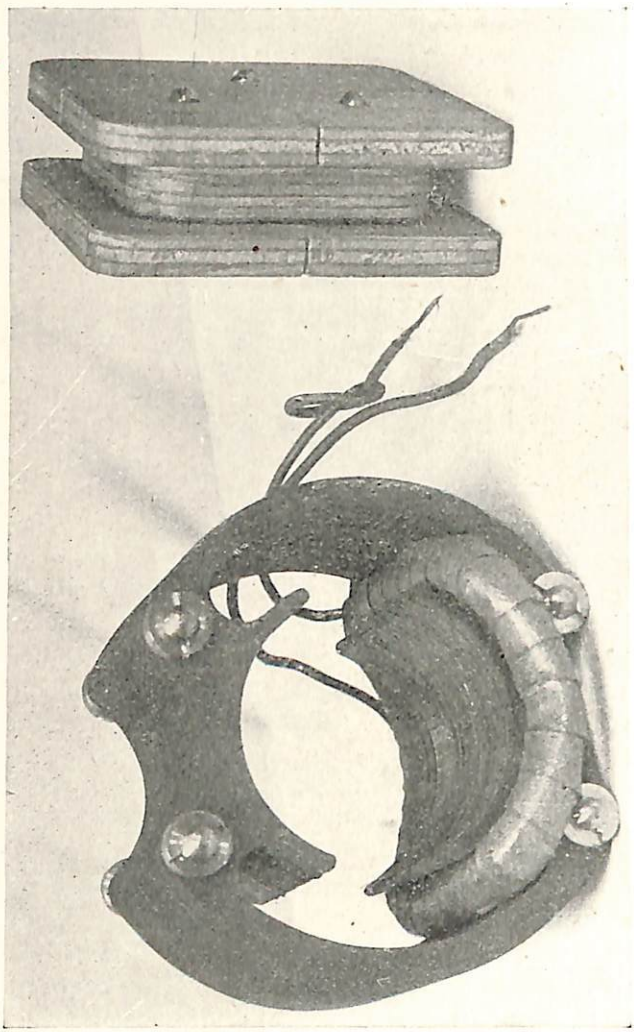


FIG. 62.—THE ASSEMBLED FIELD MAGNET WITH ONE OF THE FIELD COILS IN POSITION.
The wooden former on which the coils are wound is also shown.

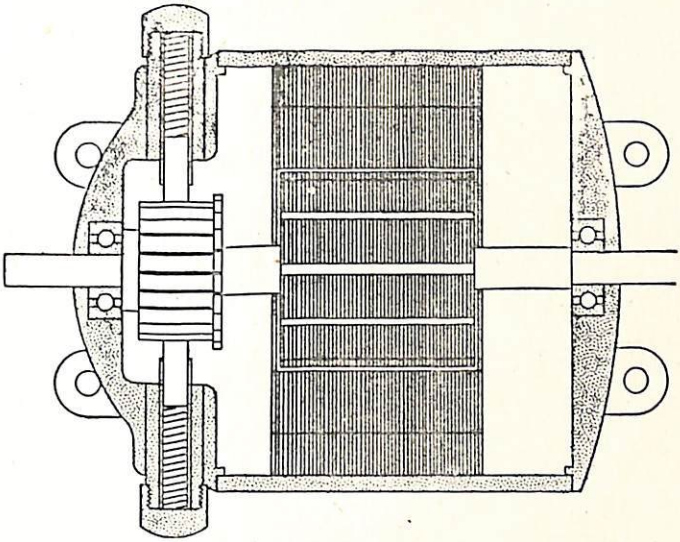


FIG. 63.—HORIZONTAL SECTION OF THE MOTOR SHOWING THE CONSTRUCTION OF THE BRUSH-GEAR AND THE MOTOR CASING.

insulating varnish or a dab of Chatterton's compound. Two turns of tape are ample.

Armature Cheek Insulation.

Two presspahn washers $1\frac{1}{2}$ inch diameter and $\frac{1}{32}$ inch thick are now cut and clamped between two spare stampings. The presspahn is then cut round the slots so that two cheeks are produced exactly the same size and shape as the armature stampings. These are used to insulate the ends of the armature. The insulating cheek which goes at the commutator end must be split in order to get it in place. The presspahn cheeks are then stuck to the armature so that they register perfectly with the slots. A plain presspahn washer is

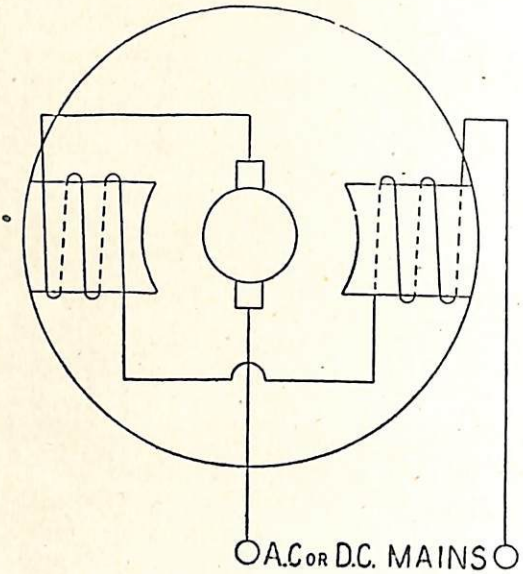


FIG. 64.—THE INTERNAL CONNECTIONS OF THE SERIES MOTOR.

The armature and the two field coils are connected all in series.

made 1-inch diameter to insulate the back face of the commutator from the end windings.

Slot Insulation.

Each slot is insulated with 0·2 mm. thick presspahn. Eleven strips $1\frac{9}{16} \times \frac{7}{8}$ inches are cut and formed into channels on a piece of $\frac{1}{8}$-inch rod. A presspahn channel is then pushed into each slot, taking care not to damage the points of the cheek insulation. The overall length of the slot insulation is the length of the armature plus the double thickness of cheek insulation. The projecting portions of the presspahn channels are then bent over with a rod, rounded at the end, as shown in Fig. 57. This gives a guide in for the conductors as they are wound on.

The Windings.

The table on page 92 gives the armature and field windings for different voltages both A.C. and D.C.

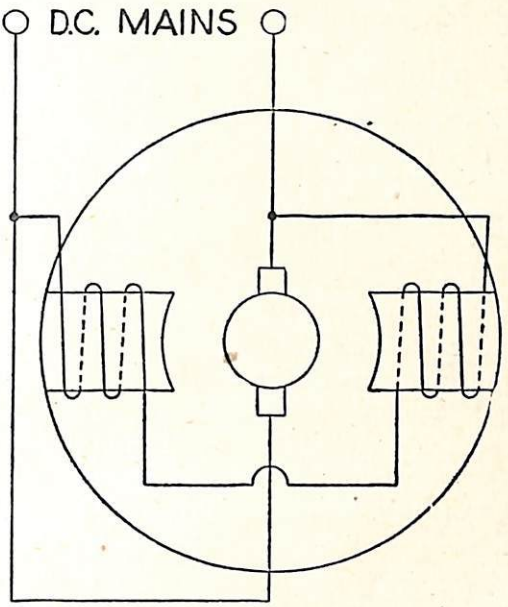


FIG. 65.—THE INTERNAL CONNECTIONS OF THE SHUNT WOUND MOTOR.

This type of machine is only suitable for D.C. supplies. The two field coils are connected in series and the ends of the field are in parallel with the armature, or brushes.

The data given for A.C. series windings may be used for D.C. of the same voltage, thereby making the motor a universal one. By using the D.C. series windings a somewhat lower speed is obtained. The D.C. series and A.C. series armatures are the same for the same voltage, but the D.C. field has more wire. The stronger field is unsuitable for A.C. operation. The shunt motor, which is used when a more constant speed machine is required, can be used on direct current only. The number of turns shown gives the data for each coil, thus for the armature there are twenty-two such coils, and for the field there are two.

The armature is wound with double silk-covered wire, but the field coils are composed of enamel-insulated wire. This arrangement gives the highest possible

efficiency consistent with good insulation. The windings are designed to give a speed of about 3,500 r.p.m. at full load output of $\frac{1}{16}$ h.p.

Fig. 60 shows a fully developed winding diagram of the armature as applied to this particular motor where the brushes are at right angles to the axis of the field magnets.

Full particulars relating to the order of winding the armature coils, and the scheme of connections to the commutator for an eleven-slot armature, are given on pages 43–65. The method of winding field coils is also given in this chapter.

THE FIELD MAGNET

The field magnet is composed of Stalloy stampings. The bore of the armature tunnel is $\frac{1}{16}$ inch larger than the armature stampings so as to give an air gap of $\frac{1}{32}$ inch. The stampings are clamped together by means of four 2 B.A. studs, with round nuts $\frac{1}{8}$ inch thick at each end. The overall length of the assembled magnet is $1\frac{5}{8}$ inch, which will take 85–90 stampings. The clamping studs must be a free fit in the holes of the stampings, or great difficulty will be experienced in threading them on. The yoke portion of the field magnet, which is the circular section connecting the two poles, has a total flux area of 1 square inch, which gives a total flux in the air gap between the armature and pole faces of 55,000 lines. The dimensions of the field magnet stampings are shown in Fig. 61.

Field Coils.

The two field coils are wound on a wooden former, which is shown in Fig. 62. The centre piece of the coil former is made from $\frac{3}{8}$-inch wood, and 2 inch square,

with the corners rounded to about $\frac{1}{8}$-inch radius. The cheeks of the former are made from $\frac{3}{16}$-inch or $\frac{1}{4}$-inch plywood, and four saw cuts are made to take the thread for tying up the coils. The centre piece of the former must be well tapered to facilitate removing the wound coil. This is more especially important for the fine wire coils of the shunt-wound motor. When the coils have been wound two flexible leads are soldered to the ends of each coil. The flexible lead which is connected to the start of the coils is knotted so that the direction of the winding is easily identified after the windings have been insulated with empire tape. The two field coils are then placed in position on the field magnet, and the coils bedded well down on the pole pieces. The ends of the coils are bent outwards as far as they will go, so as to draw the coils up tightly. The field coils are held in position by means of two soft iron strips. These are first bent a U-shape, so that the inside measurement of the U-pieces is $1\frac{5}{8}$ inch. The limbs of the U-pieces are then passed between the ends of a coil and the pole piece. Finally, the projecting ends of the strip are bent over the ends of the field coil, thus firmly retaining it in position. A piece of 0·2 mm. presspahn is inserted between the strip and the coil to prevent the sharp edges of the iron strip from cutting the insulation of the field winding. Fig. 62 shows one field coil in position.

The Motor Casing and Magnet.

The motor case, or frame, which houses the laminated field magnet, the brush gear and the armature, consists of three castings. The casting which houses the field magnet is a plain cylindrical tube $2\frac{3}{4}$ inch long and $\frac{1}{8}$ inch thick. The inside diameter of the tube is made

to fit the outside diameter of the field stampings, as shown in Fig. 63. The end-frames are turned with spigots which fit the inside of the cylindrical shell of the motor. When turning the motor end-frames, the spigots and the ball-race housings are turned at the same setting so as to ensure the concentricity of the armature with the field poles. The end-frames are secured to the body casting by means of small blocks screwed to the cylinder which are located so as to avoid the end-windings of the field coils.

The commutator end-frame is differently designed from the pulley end of the motor. It has two bosses which carry the brush gear. These are drilled out $\frac{7}{16}$-inch diameter as indicated in the sectional drawing, Fig. 63.

The field magnet assembly is located $\frac{3}{8}$ inch from the commutator end of the cylindrical housing. The stampings are fixed in position by four 4 B.A. screws, which pass through the casing into the yoke of the magnet. The holes are drilled in the casing first with a No. 27 drill, and then with the stampings in position the location of the tapped holes is marked through with the same drill. The magnet is then removed, and the four holes drilled $\frac{1}{4}$ inch deep with a No. 32 drill, and tapped out 4 B.A.

Brush-Gear.

The brush-gear consists of two $\frac{3}{16}$-inch square carbon brushes which run in square brass tubes, each $2\frac{1}{8}$ inch long. The metal brush holders are insulated from the frame of the motor by ebonite tubes, $\frac{7}{16}$ inch outside. The metal portion of the brush holders is made to project $\frac{3}{16}$ inch beyond the ebonite, so that the connections to the brushes can be made inside the motor. The part of the brush holder which projects beyond the

motor casing is threaded to receive an ebonite cap, which serves to retain the brush tension spring. The grade of the brushes is Link EG4.

Connecting the Field Coils.

The internal connections of the series wound motor are shown in Fig. 64. The two field coils are connected in series so that the two poles of the magnet are of opposite polarity. This means that when the coils are viewed from one side, the current must flow in the same direction round each pole piece. The field windings are connected in series with the brushes.

The connections between the brushes and the field coils for the shunt motor are shown in Fig. 65. The interconnection of the two field coils is the same as for the series motor, but the ends of the field winding are directly across the mains in shunt, or parallel, with the brushes.

CHAPTER V

TYPICAL DESIGN FOR A $\frac{1}{8}$-H.P. SQUIRREL CAGE INDUCTION MOTOR

AN induction motor has been chosen for the sake of simplicity of construction. The armature winding is formed by twenty-three copper bars connected together by end rings. An actual motor has been built from the specification given and has given satisfactory results on test.

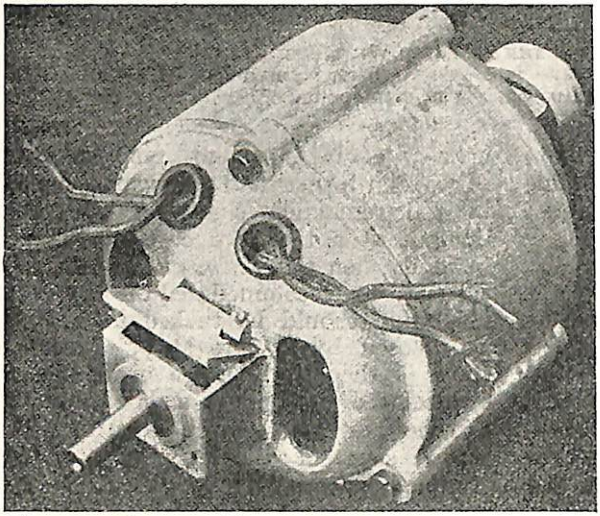


FIG. 66.—GENERAL VIEW OF THE COMPLETED MOTOR.
The leads to the starting winding are on the left.

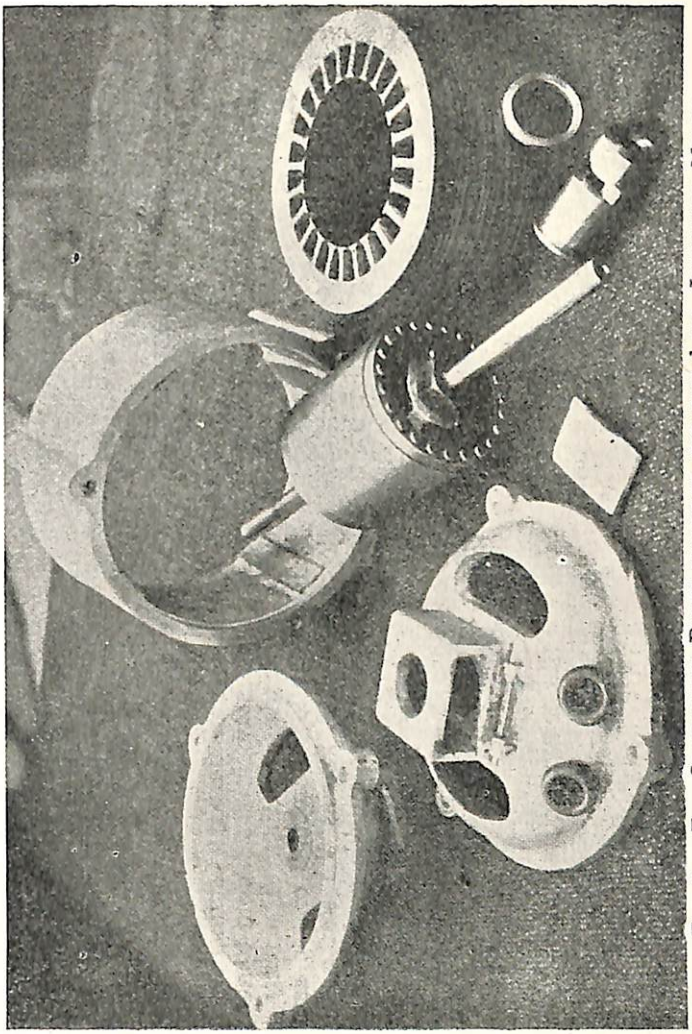


FIG. 67.—THE COMPONENT PARTS REQUIRED FOR THE $\frac{1}{8}$-H.P. INDUCTION MOTOR.

MATERIALS REQUIRED FOR CONSTRUCTION

Castings :

2 end covers (aluminium).
1 outer casing (aluminium).
2 bearings (gunmetal).
2 lubricator rings (brass).
2 lubricator covers (aluminium).
2 rotor spiders (aluminium).
2 rotor short-circuiting rings (copper).

Stampings :

8 dozen stator stampings, as specified.
8 dozen rotor stampings, as specified. } Stalloy.

Wire and Insulating Material :

1¼ lb. No. 25 S.W.G. copper wire, enamelled and single cotton covered.
½ lb. No. 32 S.W.G. copper wire, double cotton covered.
6 ft. No. 8 S.W.G. copper wire, bare.
1 sheet 10 mils. (0·010 inch) leatheroid, 10 × 9 inches.
1 sheet vulcanized fibre, 32 mils. (0·032 inch) thick, size 6 × 3 inches.
6 yards cotton tape, ½ inch wide.
2 yards 5-amp. flex.
2 inches ebonite rod, 1 inch diameter.

Raw Metallic Material :

1 foot $\frac{9}{16}$-inch round bright mild steel.
1 foot ⅛-inch round bright mild steel.
3 inches $\frac{1}{16}$-inch brass pin wire.
½ inch $\frac{3}{16}$-inch round bright mild steel.
2 mild steel nuts, tapped ½-inch, 26 threads per inch.
3 mild steel bolts, ¼-inch diameter, 3¾ inches long under head.
3 ¼-inch Whitworth nuts for the above.
2 $\frac{7}{16}$-inch steel washers.
2 $\frac{11}{32}$ × 1¼ inch split pins.

Small quantity of tinman's solder, Chatterton's compound, oil-resisting varnish for windings, and paint for motor metalwork.

In Fig. 67 is an assembly of the various components. These may be divided into four main heads :

(*a*) The stator stampings corresponding to the field magnets of a D.C. machine ;

(*b*) The rotor assembly and shaft ;

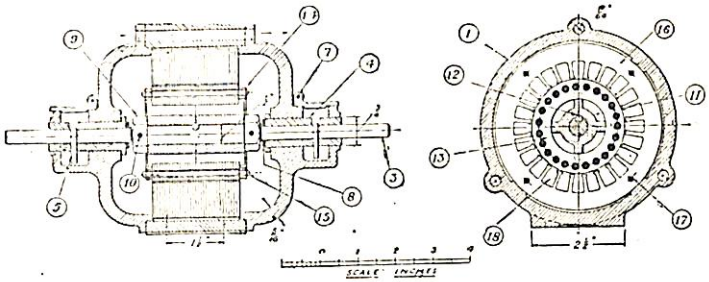


FIG. 68.—THE GENERAL ARRANGEMENT OF THE VARIOUS COMPONENTS.

(*c*) Body casting in aluminium;
(*d*) End covers (aluminium) with bearings and lubricators.

From the photograph and the general arrangement drawing it will be seen that to avoid machining a large surface and to facilitate the fitting of the stator stampings in the machine body, the latter casting has four internal facings or "lands" $\frac{1}{2}$ inch wide and raised $\frac{1}{16}$ inch above its inner surface. They are also of slight value in cooling as air may circulate more readily through the machine when running.

The End Covers.

The end covers are provided with oil-boxes, lubrication being effected by the time-honoured ring oiler system. They are bored to receive the gunmetal bearings and spigoted into the body casting to preserve the alignment. Furthermore, this spigot serves the purpose of clamping the stator stampings and must be just long enough to bolt right home face to face with the body, and at the same time grip the stator. It will be found that there is a certain amount of springiness in this group of stampings, sufficient to

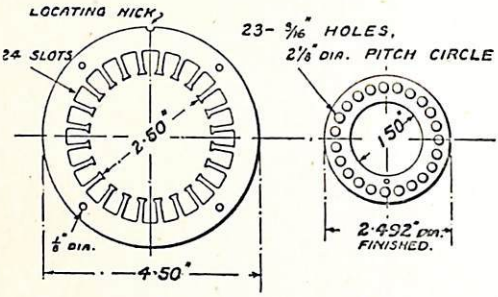


FIG. 69.—DETAILS OF THE STAMPINGS.

allow enough latitude in fitting. The rotor is again of Stalloy stampings of the same depth, viz. $2\frac{1}{4}$ inch, as the stator, but 2·492 inch diameter outside as compared with the latter's 2·500 inch inside diameter. The air-gap of 0·004 inch obtained is a rather close one which will make for efficiency though 0·006 inch or even 0·010 inch could be tolerated.

How the Stampings are Supported on the Shaft.

The stampings are supported on the shaft by a pair of cast aluminium spiders secured by a snug instead of the usual key and keyway, and bolted up from each end. It will be noted that the shaft is extended beyond the rotor at each end so that the drive may be taken from either side.

CONSTRUCTION

Riveting Up the Stator Laminations.

Eight dozen laminations will make up the $2\frac{1}{4}$ inch depth required for the stator. As they are

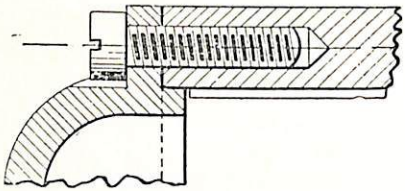


FIG. 70. — SHOWING ALTERNATIVE METHOD OF SECURING THE END COVERS.

very accurately stamped and quite flat, there will be no difficulty in obtaining a smooth assembly if certain points are watched. On the edge of each plate will be found a small nick from which they may be registered up. One side is covered with a whitish insulating compound ("Insuline") whose purpose is to prevent eddy currents straying from one lamination to the next.

The notch will be found very convenient for location and each stamping should be placed the same way up on the last, in the correct register, so that the notches resolve themselves into a long groove. The position of these notches can just be seen on the extreme right in Fig. 67. Before riveting up through the four holes provided, check the depth by lightly squeezing the stampings up in the vice or clamp. Soft iron rivets should be used, and any slight burrs on the outside of the assembly cleaned off with a file.

Machining the Outer Casting.

The overall diameter of the body casting being a little under 6 inch, it may be swung in a 3-inch lathe.

The facing and boring is a face plate job for a small lathe, and the casing bolt holes are convenient for bolting the job up during this operation. It may be necessary to drill special holes in the face plate to accommodate these, but this is an advantage as the same holes may be used for mounting the end covers. There are two alternatives open in the matter of casing bolts, i.e. through bolts, a clearance fit through the carcase or stud bolts tapped into it. In either case, they should be ¼ inch diameter. If the former method is adopted, first mark out the casing carefully on each side, drill $\frac{3}{16}$ inch for a depth of about ⅛ inch

and tap $\frac{1}{4}$ inch Whitworth. Short set-screws through the face plate screwed into these holes will then secure the casting rigidly enough for ensuing operations, the holes being afterwards drilled through $\frac{1}{4}$ inch clearance.

The Internal "Lands."

When the casting is rigged up for the first machining operations, the internal "lands" should be carefully bored to a good fit with the stator stampings and these should be tried in several positions in case they are not quite in register at some particular spot round their periphery. Before this casting is removed, face the ends, and counterbore to $4\frac{3}{4}$ inch diameter, for a depth of $\frac{3}{16}$ inch full.

Jigging the Carcase Casting.

The corresponding counterbore at the reverse end *must* be quite concentric with the first. Some form of jig to locate the as yet unfinished casting is essential, and a thin disc of brass or aluminium bolted through the face plate suggests itself.

The End Covers.

The end covers should be marked out and drilled to suit the carcase and using the same holes bolted to the face plate, bored $\frac{3}{4}$ inch for the bearing bush, and the front boss faced. Here, again, before the work can be reversed for turning the spigot, an arbor, held either in the chuck or between centres, must be made up in order to ensure perfect alignment of the rotor and stator. The gunmetal bearings are a plain turning job, but a point to watch is the relieving of the sharp corner at the inside shoulder about $\frac{1}{64}$ inch for a length of $\frac{1}{32}$ inch.

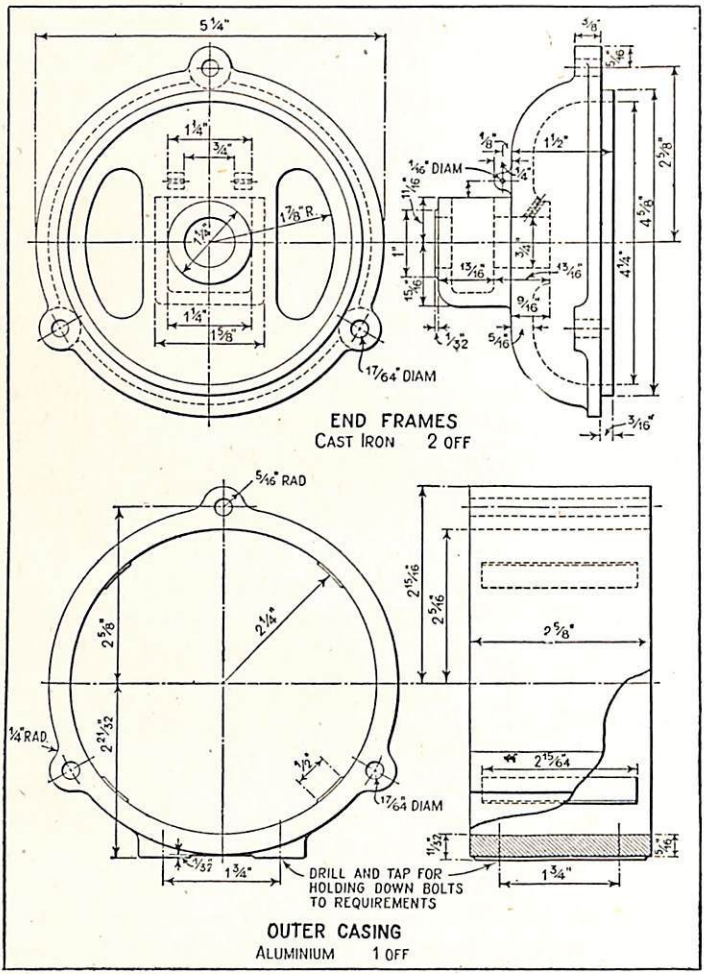
When machining is completed the oiler slot is filed away far enough to allow a clear run for the oiling ring when resting on the shaft. Oil ways leading from this slot towards each end of the bush should be cut with D-shaped chisel, finishing in an annular groove whose purpose is to prevent the lubricant working out.

The Rotor.

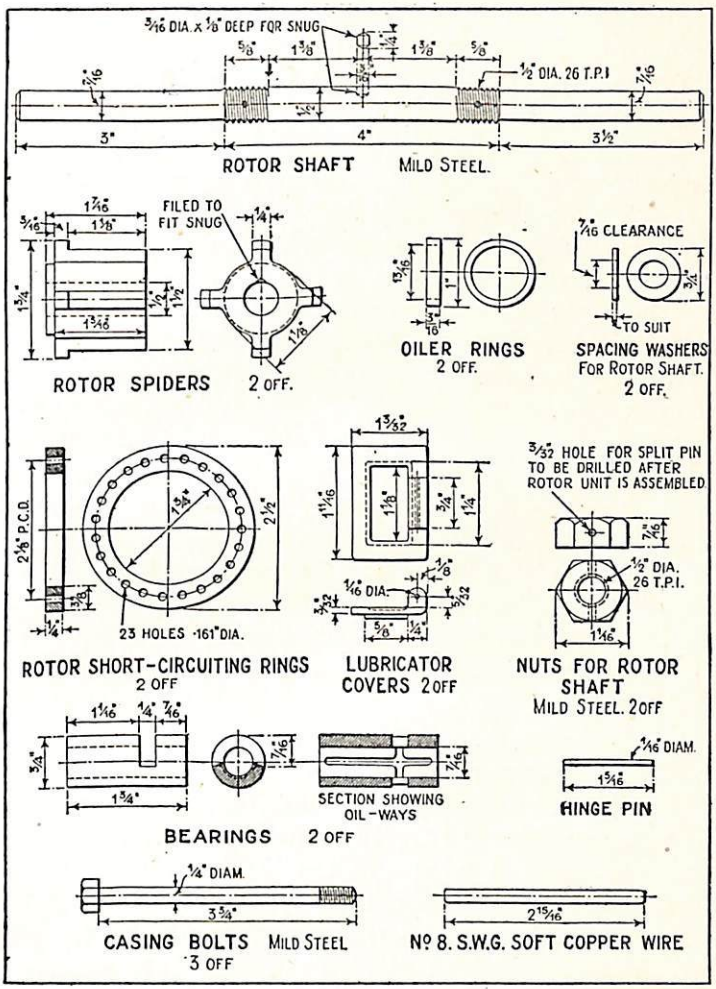
The main work on the carcase is now complete, and the rotor assembly should next be tackled. The rotor-shaft is a straightforward between centres job on which little comment is necessary. If a travelling steady is available it should be used, and in any case the last few cuts must be very light and the tail-stock adjusted if the lathe has any tendency to turn tapered.

A length of 4 inch (bare) in the centre of the shaft is left $\frac{1}{2}$ inch diameter, and screw cut 26 T.P.I. at each end for a length of $\frac{1}{2}$ inch while the rest is reduced to $\frac{7}{16}$ inch, a good running fit on the bearings. A shallow hole $\frac{3}{16}$ inch diameter accommodates the snug or "dutchman."

The rotor spiders are best held in a four-jaw chuck for boring and facing the inner surface, after which the arms of the "star" may be turned to fit the rotor stampings either on a special arbor or on their own shaft. The final fitting of the snug should be left until the stampings are ready for assembly. There must be just sufficient stampings to allow the two halves to press firmly against them and at the same time engage the snug with no trace of looseness. A badly fitting snug will be a constant source of trouble and may eventually fail.



FIGS. 71 AND 72.—SHOWING DIMENSIONS OF THE END FRAMES AND OUTER CASING.


3/16 DIA. x 1/8 DEEP FOR SNUG
1/2 DIA. 26 T.P.I.
ROTOR SHAFT MILD STEEL.
FILED TO FIT SNUG
ROTOR SPIDERS 2 OFF.
OILER RINGS 2 OFF.
7/16 CLEARANCE
TO SUIT
SPACING WASHERS FOR ROTOR SHAFT. 2 OFF.
2 1/8" P.C.D.
23 HOLES .161" DIA.
ROTOR SHORT-CIRCUITING RINGS 2 OFF
1/16 DIA.
LUBRICATOR COVERS 2 OFF
3/32 HOLE FOR SPLIT PIN TO BE DRILLED AFTER ROTOR UNIT IS ASSEMBLED
1/2" DIA. 26 T.P.I.
NUTS FOR ROTOR SHAFT MILD STEEL. 2 OFF
SECTION SHOWING OIL-WAYS
BEARINGS 2 OFF
1/16 DIAM.
HINGE PIN
1/4" DIAM.
CASING BOLTS MILD STEEL 3 OFF
Nº 8. S.W.G. SOFT COPPER WIRE

FIGS. 73–75.—SHOWING DIMENSIONS AND DETAILS OF VARIOUS PARTS OF THE MOTOR.

The Short Circuiting Rings.

A pair of copper rings will be required drilled with 23 holes 0·161 inch diameter (No. 20 drill) at $2\frac{1}{8}$ inch diameter pitch circle. In the absence of a dividing head a single stamping makes an excellent jig for marking out the holes. The two rings should be clamped together and drilled without parting, and two locating marks made for reference when the time comes for the final assembly.

The 23 $2\frac{15}{16}$-inch long rotor bars should be cut from No. 8 S.W.G. copper wire, previously softened, if necessary, and the assembling of the rotor can then be commenced.

Assembling the Rotor.

As in the case of the stator laminations, a small locating hole will be found in each rotor stamping, through which a piece of thin copper wire may be temporarily threaded to keep the stampings in place, but it is important that no further riveting shall be commenced until the laminations are safely on the spiders.

The exact number will have to be arrived at by trial and error. It must be remembered that once the bars are in position the snug cannot be got at save by completely dismantling the whole rotor. The same precautions with regard to the insulated side of the stampings should be observed as in the case of the stator. Having got the laminations safely housed on the spiders and clamped up by the shaft nuts, the riveting up of the rotor bars can be proceeded with. Do not forget location marks on the short circuiting rings. The actual riveting may be a two handed job

unless the vice jaws are used as an anvil, but care should be taken not to damage or bend the shaft. The ends of the bars must be scrupulously clean to ensure a good electrical connection (the more complete the short circuiting the higher the efficiency) and also to facilitate the subsequent soldering up. When the heads have been brought over a final shaping may be accomplished with a cup-shaped "snap." As a precaution the nuts are finally drilled $\frac{3}{32}$ inch and pinned with a split cotter.

The whole job should now be heated up together with the shaft vertical and plenty of soft solder run round the heads of the rivets, dealing with one end at a time. A non-corroding flux should be used.

Reducing the Rotor to Size.

There will probably be a number of high spots and burrs standing up in the laminations which must be taken down before the rotor will clear the stator teeth. However, it is best to avoid turning the surface as there will be a tendency for one lamination to be forced into good electrical contact with the next, so partially defeating the object of preventing the flow of eddy currents through the iron core. The rotor unit may be mounted in the lathe between centres and carefully filed or ground down until it is 2·492 inch in diameter, and all roughness removed. As against the 2·500-inch bore of the stator, this will provide an air gap of 0·004 inch.

Checking Rotor for Balance.

The rotor cannot be deemed complete until it has been checked for balance. As a matter of fact, if the earlier marking out and machining has been

FIG. 76.—RIVETING UP THE ROTOR BARS.

reasonably accurate, there should be little the matter with it; but even a slight error in balancing is going to make itself noticeable at 2,800 r.p.m.

A suitable rig for the purpose may be very simply improvised from two domestic knives set into a couple of pieces of 3 × 2 inch timber, as illustrated in Fig. 77. They should be very carefully checked for level both along the blades and at right angles to them before the rotor is rested across them. It will be easier to chalk the light side and then carefully remove any blob of solder or high rivet head equally from each end ring opposite the mark until the rotor shows no tendency to spin to rest in any particular place.

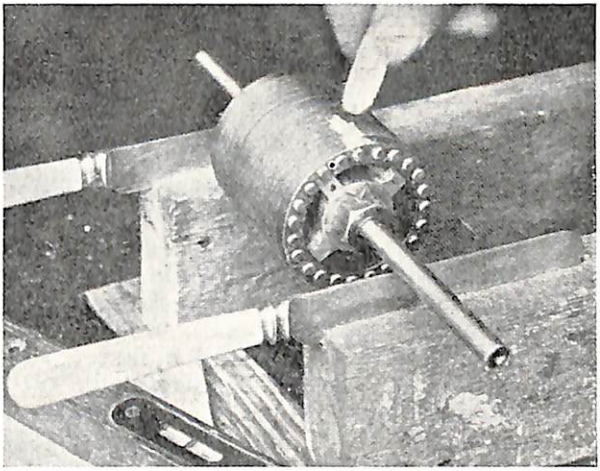


FIG. 77.—HOW TO BALANCE THE ROTOR.

A suitable rig for the purpose can be improvised from two knives set into two pieces of 3 × 2 inch timber. It will be found easier to chalk the light side and then carefully remove any blob of solder or high rivet head from each end ring opposite the mark.

It is scarcely possible to check it for dynamic balance, but as long as the static balancing is reasonably accurate no trouble should ensue.

Trial Assembly.

A trial assembly can now be made. Carefully tap the stator laminations into the casing with a wooden mallet, avoiding damage to the teeth, until it just covers the raised facings inside the casting. One end cover with bearing complete can then be slipped on, and the rotor shaft run into it. The oiler ring must, of course, be assembled at the same time as the gunmetal bearing is driven home into the casting. The other end casting is now ready for fitting and the casing bolts lightly tightened up. The rotor must run with-

out a trace of stickiness anywhere. Check the air gap for evenness at three or four points round the circumference, say at 12, 3, 6, and 9 o'clock, revolving the rotor a quarter turn each time. There should be very little variation at any point, as each part is accurately registered by the various spigots and facings, and it is unlikely that anything more than 1 or 1½ "thous" difference will be noted. The shaft should run, of course, quite freely, and the mechanical side being in order, the machine can be dissembled for winding.

Winding the Stator.

The process of winding the stator may not be anticipated with much keenness, but there is no need to be apprehensive of many difficulties. A plain two-pole winding of this type is a good deal easier to put on than, say, the winding of a drum armature, and providing a few elementary rules are followed, failures are unlikely.

For starting purposes, a separate winding is provided, placed at right angles to the running coils and switched on for an instant at starting only, and then disconnected from the mains. In Fig. 79 the disposition of the running and starting coils is illustrated, the former being shown by heavy lines and the latter by light.

The starting coils are wound with a much finer gauge of wire than the running coils, and occupy less slot space in the stator—eight slots as compared with sixteen in this machine. The difference in resistance between the two is sufficient to alter the phase of their respective currents and converts the winding temporarily into a two-phase one, biasing

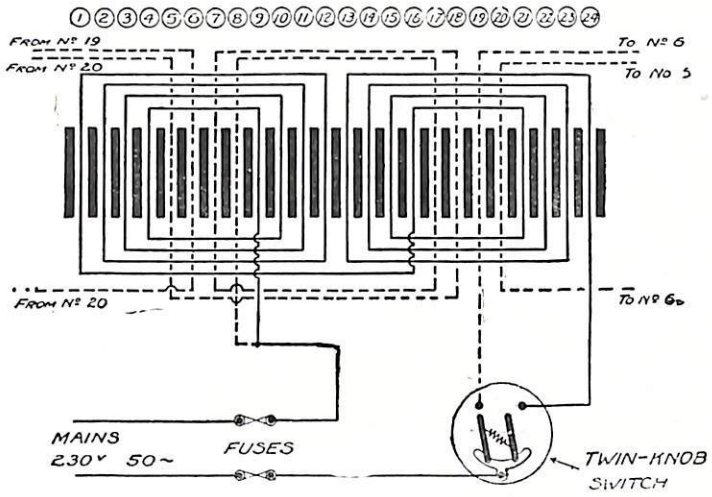

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
FROM Nº 19
FROM Nº 20
To Nº 6
To No 5
FROM Nº 20
To Nº 6
MAINS
230ᵛ 50~
FUSES
TWIN-KNOB
SWITCH

FIG. 78.—A DEVELOPMENT OR "PANORAMIC" SKETCH OF THE WINDINGS.

Note how each opposing cell-group has its direction of winding reversed when seen from the centre of the stator tunnel. The running winding is shown by full lines and the starting winding by dotted lines.

the fields in a certain direction. The rotor will pick up in speed in that direction until it is near synchronism and the auxiliary winding must then be cut out of circuit immediately.

We shall, therefore, need two separate sets of coils, producing four poles for starting and two for running. In Fig. 78 the stator is drawn as it would be photographed by a panoramic camera making a complete revolution at its centre. The teeth are represented by black rectangles and the space between them is, of course, the slot space available for housing the conductors. For the sake of simplicity each heavy line indicates not one wire, but a bundle of conductors running through that particular slot.

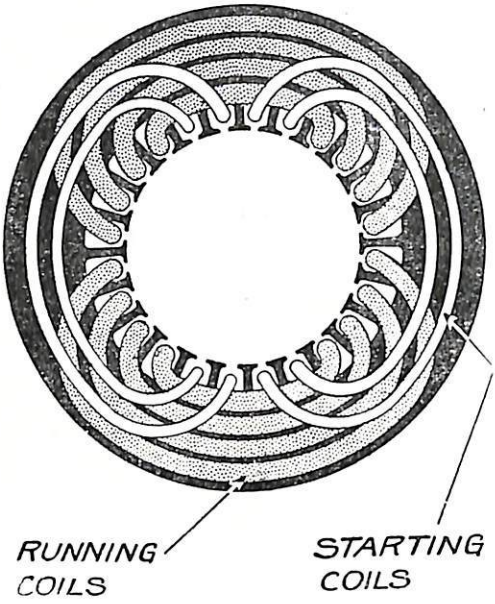


FIG. 79.—END VIEW OF THE STATOR.

Why Coils are Concentric.

It will be noticed that the coils are concentric, i.e. they are not lapped one ahead of the next, as in a drum armature winding, and, furthermore, the direction of rotation is reversed between the two pole groups. This is necessary to produce opposite poles at a spacing of 1800 degrees, considering the starting and running coils separately.

The Running Winding.

Referring again to Fig. 78 we can trace out the method of winding. Commencing with the running winding, the first coil consists of 85 turns of 25 S.W.G. wire spanning slots 9 to 4 in an anti-clockwise direction. Continuous with this are a further 85 turns each between slots 10 and 3, 11 and 2, and 12 and 1, all in the same direction. The end leading from No. 1 is continued to the opposite side of the stator and 85

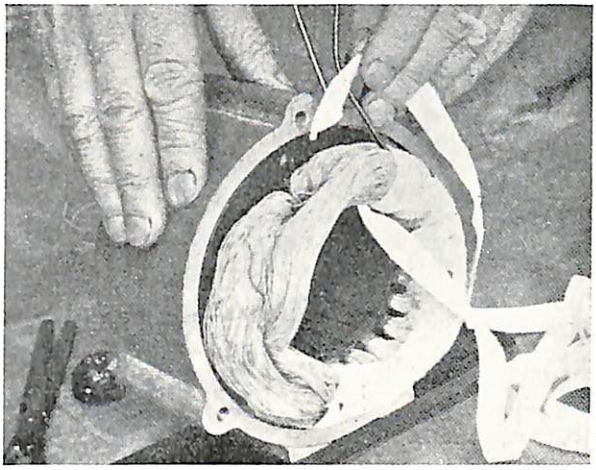


FIG. 80.—TAPING THE FINISHED WINDINGS.

Plain white linen tape is employed here, secured at intervals with a touch of Chatterton's compound.

clockwise turns laid between slots 16 and 21, 15 and 22, 14 and 23, and 13 and 24.

The Starting Winding.

The starting turns are accommodated in the remaining eight slots. The 32-gauge wire is used here, and the first two coils to lay on are Nos. 8 to 17 and 7 to 18 (clockwise), 150 turns each. The end leading from No. 18 is passed across to No. 20 slot and is used to start the last two coils, 20 to 5 and 19 to 6, again 150 turns per slot, but wound in an anti-clockwise direction.

The accompanying table gives the details of a winding for 220 to 250 volts, 50-cycle single phase supply :

Running winding	Gauge of wire . .	25 S.W.G. enamelled and single cotton covered
	Conductors per slot	85
	Slots per complete coil	8
	Coils per phase .	2
Starting winding	Gauge of wire . .	32 S.W.G. double cotton covered
	Conductors per slot	150
	Slots per complete coil	4
	Coils per phase .	2

What to Do Before Winding is Begun.

Before winding is begun, the slots are numbered from 1 to 24 to conform to the developed winding diagram and assist in tracing the connections. Each slot must be lined with a strip of 10-mil leatheroid, cut to such a length as to overhang at each end about $\frac{1}{8}$ inch and wide enough to cover the whole inside surface and be flared out at the slot opening as shown in Fig. 82.

The protection this offers will prevent damage to the wire as it is slipped into the narrow space between the teeth; the ends can be trimmed after the slot has been filled, folded in and the opening closed with a strip of $\frac{1}{32}$-inch fibre $2\frac{1}{4}$ inch long by $\frac{3}{16}$

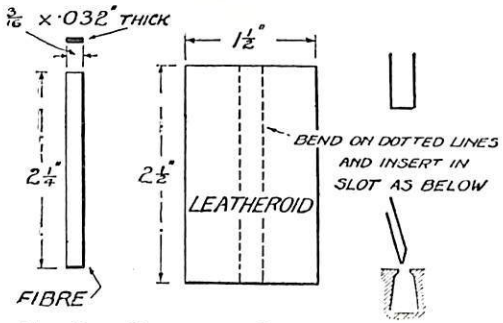


FIG. 81.—DETAILS OF INSULATION FOR THE STATOR SLOTS.

inch wide, which will effectively prevent any wire becoming displaced in subsequent service.

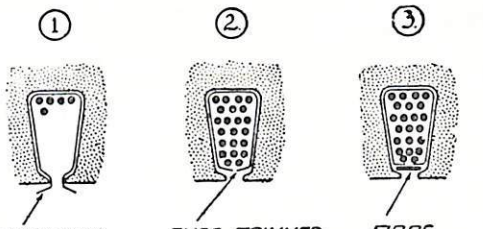


FIG. 82.—HOW THE STATOR SLOTS ARE INSULATED.

Important Points to Remember.

Having studied Figs. 78 and 79, the actual winding can be started. The most important fundamentals are as follows:

Never let the wire get kinked; work the wire gently into the space between the stator teeth without resort to hammering; and, finally, do not damage the insulation.

For the running coils enamelled and single cotton covering has been specified. For amateur use it forms an ideal insulation, far superior to plain enamelled covered, though a good deal more expensive. The single cotton covering affords a strong fibrous insulation, is quite difficult to damage and at the same time takes up less space than the common double cotton covering.

First, the Running Coils.

The running coils should be tackled first. It will be found easier to handle the stator if it is slipped into the body casting and all subsequent operations performed with the two units assembled. It is really quite immaterial where the windings are begun, so

long as the coil pitch is correct. Hand winding is best for these coils as the natural stiffness of the 25-gauge wire is sufficient to keep the turns in place. The bobbin should not be passed through the stator tunnel, but a loop of wire formed and one conductor at a time fed into its particular slot. The end or "dead" turns not enclosed by the stator iron must be carefully formed to a small arc and not pulled tightly to a sharp corner, but if too much wire is left here it may be difficult to house the bundles in the end covers.

Now the Starting Coils.

The starting coils are best wound on two sizes of wooden former and afterwards housed in the remaining slots. A few conductors at a time are carefully slipped in, and when the whole of one side of a coil has been accommodated the leatheroid insulation should be tucked in and the slot closed by a fibre strip. However, there is the disadvantage of having to connect the appropriate ends of the coils together in the correct polarity. The actual sizes of the formers are best obtained by trial, as much will depend on the running winding previously laid on.

Testing Polarity of Windings.

It is a wise precaution to test with a compass needle. Deal with the starting and running windings separately. Connect the leads of one of these to a 2- or 4-volt accumulator, and with the stator lying horizontally on the bench, lower a small compass needle into the bore, keeping it quite close to the stator teeth. As the needle is passed round, it should indicate two quite definite unlike poles at 180 degrees to each other,

concentrated at the centre of the appropriate winding.

If everything is in order, the remaining winding may be dealt with in the same way, and the end turns taped. For this purpose plain white linen tape ½ inch broad will answer very satisfactorily, and may be held in place by a touch of Chatterton's compound where required.

The stator can then be thoroughly dried out in an oven before the windings are "doped." It is important from the point of view of insulation to dispel any moisture in this way first. Any good oil-resisting varnish may be used, applied quite liberally and allowed to run right down into the slots from each side.

Assembly of Motor.

The motor is now ready for assembly. Be careful not to damage the windings as the end covers are put on. When tightened up they should clear the winding by a fraction of an inch, but if there is any tendency for the windings to be squeezed up, a layer of thin presspahn round the inside of the covers will obviate a possible "short" to earth. The starting and running coil leads may be brought out through insulating bushes in the end covers direct to the switchboard, or, alternatively, via an insulated terminal box.

Cutting Out the Auxiliary Winding.

As previously mentioned, the auxiliary winding is required only for a short time while the motor is speeding up, after which it must be cut out of circuit. The easiest way of accomplishing this is by means of a special type of switch known as the "twin knob." In appearance it is similar to a tumbler lighting switch,

with the exception that there are two levers, one recessed into the other, which control two sets of contacts. While the hand is on the switch, both knobs are operated, and the starting and running circuits are made simultaneously, but when the hand is removed the inner knob is returned by a spring and breaks the starter circuit.

Connections to Mains.

The actual connections to the mains are shown in the winding diagram, Fig. 78. There is always a momentary rush of current at starting, amounting to four or five times the full load current, i.e. 3 to 4 amperes. The supply leads must therefore be fused to at least 5 amperes, but there is no reason why the machine should not be run from lighting mains if required in a portable capacity such as for fan-driving.

CHAPTER VI

HOW TO DESIGN SMALL POWER TRANSFORMERS

THE design of small power transformers of outputs ranging from 10 to 1,000 volt-amperes is simplified here so that the essential data of any particular size of transformer is quickly found by reference to the tables given.

The First Consideration.

The first consideration in the design of any transformer is the output. The output is stated in so many volt-amperes, because in alternating current apparatus it is not usual to speak of an output in watts. This is because the volts multiplied by the amperes, in an alternating circuit, do not always give the true watts. For most purposes, however, the watts output of a small transformer will be the product of the volts and amperes.

Estimating the Output of a Transformer.

To estimate the output of a transformer consider a practical example. A battery charger is to have a rectifying valve requiring 45 volts at 3 amperes, and a filament winding of 1·8 volts at 5·5 amperes. The transformer is to be connected to a 230-volt, 50-cycle

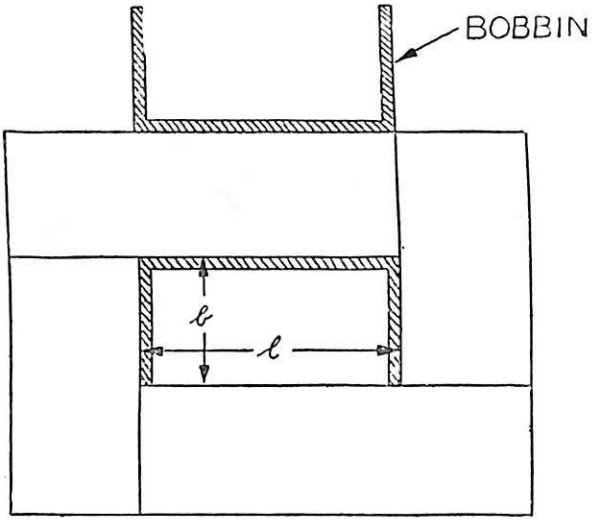


FIG. 83.—A TRANSFORMER CORE BUILT UP FROM STRIPS OF STALLOY.

Each succeeding layer of strips is arranged to bridge the previous layer. The product of l and b gives the gross winding area of the transformer.

supply. The output of this transformer is found as follows:

$$\begin{aligned} 45 \times 3 &= 135 \text{ volt-amperes} \\ 1{\cdot}8 \times 5{\cdot}5 &= \underline{\ 10} \text{ volt-amperes} \\ &\underline{\underline{145}} \text{ volt-amperes.} \end{aligned}$$

Thus the output is determined by multiplying the volts by the amperes, and, where there is more than one output winding, the total output is found by adding together the separate outputs. It will be seen from the example given that the nature of the supply does not enter into the calculation of the output.

Core Section.

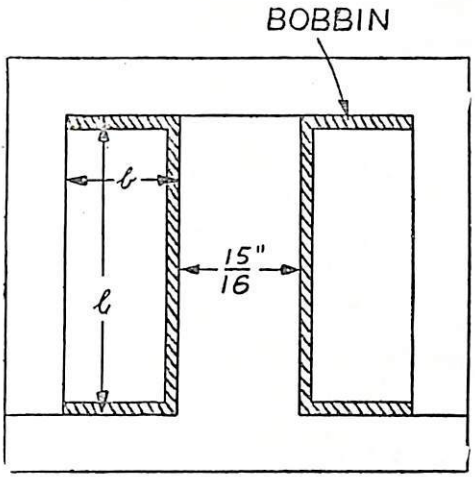


FIG. 84.—A TRANSFORMER CORE WITH BOBBIN IN POSITION BUILT FROM STANDARD T-U STAMPINGS.

In the example discussed in this chapter $l = 2\frac{5}{8}$ inches and $b = \frac{5}{8}$ inch. The product of l and b gives the winding area for this type of core.

When the total output of the transformer has been determined, the next consideration is the sectional area of the core. The core of a transformer is that part of the iron on which the coils are wound. The yoke of the transformer, or that part of the iron outside the coils, must have a total cross-sectional area at least equal to the area of the core. A simple rectangular core has a uniform section, the coils being wound on one side of the rectangle. In the more usual arrangement of T-U stampings the core section is twice the area of the yokes since there are two paths for the magnetic flux from the ends of the core. Figs. 83 and 84 show the difference between the two types of cores.

A Trouble-Saving Table.

The mathematical determination of the optimum area of the core is extremely complicated and the best average values are given for outputs of 10–1,000 volt-

TABLE IX

SHOWING BEST AVERAGE VALUES OF CORE AREA FOR OUTPUTS OF 10–1,000 VOLT-AMPERES

Output (Volt-amperes).	Core Section (Square Inches) Stalloy.				Approx. Winding Area (Square Inches).
	25 Cycles.	40 Cycles.	50 Cycles.	60 Cycles.	
10	0·6	0·4	0·3	0·25	$\frac{5}{8}$
15	0·8	0·5	0·4	0·3	$\frac{3}{4}$
20	1·0	0·6	0·5	0·4	$\frac{7}{8}$
25	1·25	0·75	0·6	0·5	$\frac{7}{8}$
50	2·0	1·25	1·0	0·8	1
75	2·5	1·5	1·25	1·0	$1\frac{1}{4}$
100	3·0	1·75	1·5	1·25	$1\frac{3}{8}$
125	3·25	2·0	1·75	1·5	$1\frac{1}{2}$
150	3·5	2·25	1·75	1·5	$1\frac{5}{8}$
175	4·0	2·5	2·0	1·75	$1\frac{3}{4}$
200	4·0	2·5	2·0	1·75	$1\frac{7}{8}$
250	5·0	3·0	2·5	2·0	2
300	5·0	3·25	2·5	2·5	$2\frac{1}{4}$
350	6·0	3·5	3·0	2·5	$2\frac{3}{8}$
400	6·0	3·75	3·0	2·5	3
450	6·5	4·0	3·25	2·75	$3\frac{1}{8}$
500	7·0	4·5	3·5	2·75	4
750	8·0	5·0	4·0	3·5	5
1,000	9·0	6·0	4·5	3·75	$5\frac{3}{4}$

amperes in Table IX. It will be seen from Table IX that the sectional area depends on two factors, the output and the frequency of the supply mains. To continue with the design of the practical example, where an output of 145 volt-amperes is required, refer to Table IX and choose the next largest output, which is 150 volt-amperes. If the frequency of the supply is 50 cycles, the core section will be 1·75 square inches of Stalloy transformer steel. The area of the core, for a given output, is inversely proportional to the frequency of

TABLE X

GIVING SIZES AND QUANTITIES OF STAMPINGS FOR VARIOUS CORE SECTIONS

Sectional Area of Core (Square Inches).	Turns per Volt.				Actual Size of Core (Inches × Inches).	Stampings.	
	25 Cycles.	40 Cycles.	50 Cycles.	60 Cycles.		Width of Tongue (Inches).	Quantity 0·014 Inch Thick.
0·25	—	—	—	23·3	½ × ⅛	½	36
0·3	—	—	23·3	19·5	½ × 1/10	½	36
0·4	—	22·0	17·5	14·6	½ × ¼	½	48
0·5	—	17·5	14·0	11·7	½ × ¼	½	48
0·6	23·4	14·6	11·7	9·75	⅝ × ¼	⅝	56
0·7	20·0	12·5	10·0	8·35	⅝ × ⅜	⅝	56
0·8	17·5	11·0	8·75	7·3	1/10 × ⅜	1/10	60
0·9	15·6	9·75	7·8	6·5	1 × 1	1	64
1·0	14·0	8·75	7·0	5·85	1 × 1⅛	1	71
1·25	11·2	7·0	5·6	4·7	1¼ × 1⅛	1¼	71
1·5	9·3	5·85	4·65	3·9	1¼ × 1⅜	1¼	88
1·75	8·0	5·0	4·0	3·34	1¼ × 1⅝	1¼	96
2·0	7·0	4·37	3·5	2·92	1¼ × 1⅝	1¼	100
2·25	6·2	3·9	3·1	2·6	1⅜ × 1⅝	1⅜	104
2·5	5·6	3·5	2·8	2·34	1⅜ × 1¾	1⅜	112
2·75	5·1	3·2	2·5	2·13	1¾ × 1¾	1¾	112
3·0	4·7	2·9	2·33	1·95	1⅞ × 1⅞	1⅞	120
3·25	4·3	2·7	2·16	1·8	2 × 1⅞	2	120
3·5	4·0	2·5	2·0	1·67	2 × 2	2	128
3·75	3·74	2·34	1·86	1·56	2 × 2⅛	2	136
4·0	3·5	2·2	1·75	1·46	2 × 2¼	2	144
4·5	3·1	1·95	1·55	—	2¼ × 2¼	2¼	144
5·0	2·8	1·75	—	—	2¼ × 2½	2¼	160
5·5	2·54	1·59	—	—	2½ × 2½	2½	160
6·0	2·34	1·46	—	—	2½ × 2⅝	2½	176
6·5	2·15	—	—	—	2⅝ × 2¾	2⅝	176
7·0	2·0	—	—	—	2¾ × 2⅞	2¾	184
7·5	1·97	—	—	—	2⅞ × 3	2⅞	192
8·0	1·75	—	—	—	3 × 3	3	192
9·0	1·56	—	—	—	3⅛ × 3½	3⅛	213

the supply. Thus the area of the core is doubled at 25 cycles, that is, 3·5 square inches for an output of 150 volt-amperes.

How Many Turns ?

When the area of the core has been found from Table IX, the number of turns on the various windings is estimated from Table X. To continue with the example design, look down column 1 for a core section of 1·75 and then across on this line to column 4. This gives a figure of 4 turns per volt. That is to say, that for every volt across a winding on this particular transformer there must be four turns. Take the primary winding first. This is to be connected to a 230-volt main, therefore the number of turns will be $4 \times 230 = 920$.

When estimating the number of secondary turns an allowance of 5 per cent. extra turns is made to compensate for the drop in volts due to the current in the windings. The 45-volt secondary winding will have, therefore, $45 \times 4 \times 1{\cdot}05 = 189$ turns. Similarly, the 1·8-volt winding has $1{\cdot}8 \times 4 \times 1{\cdot}05 = 7\frac{1}{2}$ turns.

When Extreme Accuracy is Required.

Where extreme accuracy in the voltage output is required, the resistance of the windings must be predetermined and the number of turns necessary to compensate for the drop in volts on load, or the regulation as it is called, must be calculated. An easier and more certain method is to adjust the number of secondary turns until an alternating-current voltmeter gives the desired reading when connected across the winding loaded at the normal current.

TABLE XI

SHOWING WIRE SIZES AND THEIR CURRENT-CARRYING CAPACITY AT 1,500 AMPERES PER SQUARE INCH

Current (Amperes).	Wire Size (S.W.G.).	Wire Covering.	Turns per Square Inch.
19·3	10	Double Silk	57
15·8	11	,,	69
12·7	12	,,	85
9·9	13	,,	108
7·5	14	,,	139
6·1	15	,,	172
4·8	16	,,	213
3·7	17	,,	272
2·7	18	,,	376
1·9	19	Enamel	560
1·5	20	,,	680
1·2	21	,,	865
0·92	22	,,	1,110
0·68	23	,,	1,510
0·57	24	,,	1,775
0·47	25	,,	2,120
0·38	26	,,	2,560
0·32	27	,,	3,120
0·26	28	,,	3,760
0·22	29	,,	4,390
0·18	30	,,	5,380
0·158	31	,,	6,060
0·137	32	,,	6,890
0·118	33	,,	7,900
0·100	34	,,	9,610
0·083	35	,,	11,250
0·068	36	,,	13,450
0·054	37	,,	16,400
0·042	38	,,	20,400
0·032	39	,,	28,250
0·027	40	,,	32,450

The Gauge of Wire.

Table XI gives the wire sizes and their current-carrying capacity at 1,500 amperes per square inch,

which is a satisfactory value for continuous working. Where the current shown in column 1, Table III, does not exactly correspond with the output current, the next highest value is taken. Thus, in the practical example, the 45-volt 3-ampere winding is wound with 17 S.W.G. D.S.C. wire, and the 1·8-volt, 5·5-ampere coil is wound with 15 S.W.G. D.S.C. wire.

Wire Covering.

The wire covering specified in Table XI gives the smallest, and consequently the most efficient, coil, consistent with good insulation. It is not generally safe to wind enamel covered wire thicker than 19 S.W.G., so that double silk covering is used for the heavier sizes. Double cotton covered wire is also suitable and may be used when the necessary extra winding space is available.

It must be remembered that when enamel insulated wire is used for coils consisting of more than two or three layers, paper insulation between the layers is necessary. This is because enamel insulation provides no resilience which is necessary to allow the winding to expand as it warms up on load.

Primary Current.

Before the gauge of wire for the primary or mains winding can be settled, it is necessary to calculate the primary current for full load. This is found by dividing the mains voltage into the output watts or volt-amperes. In the example under consideration the primary current is $\frac{145}{230} = 0{\cdot}63$ ampere, at 100 per cent. efficiency. A transformer of this size would have an efficiency of about 92 per cent., so that the primary current would

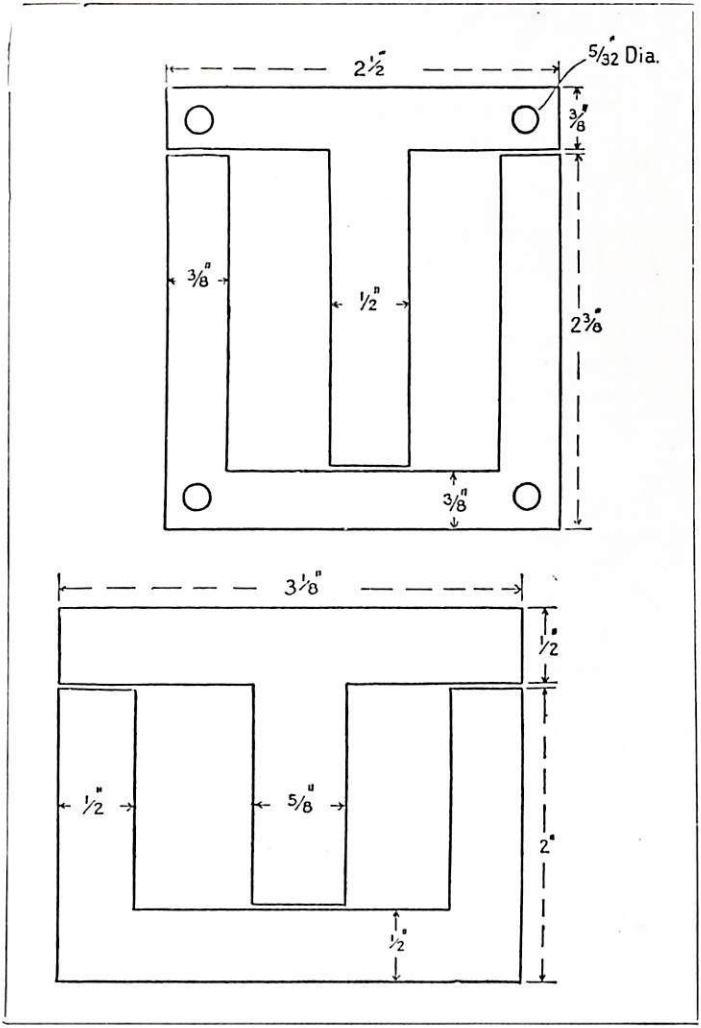


FIG. 85.—DIMENSIONS OF TYPICAL "STALLOY" LAMINATIONS FOR TRANSFORMERS AND CHOKES.

The standard thickness of "Stalloy" is 0·014 inch. These examples are selected from the range of sizes stocked by Joseph Sankey & Sons, Ltd., Bilston.

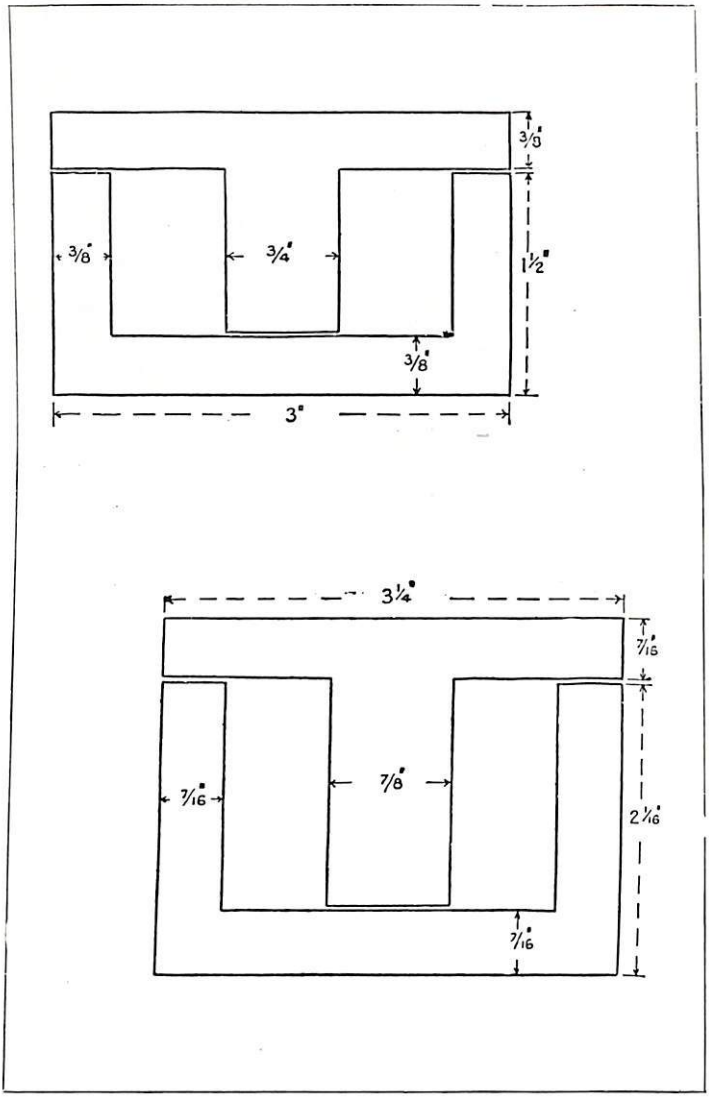


FIG. 85 (*continued*).

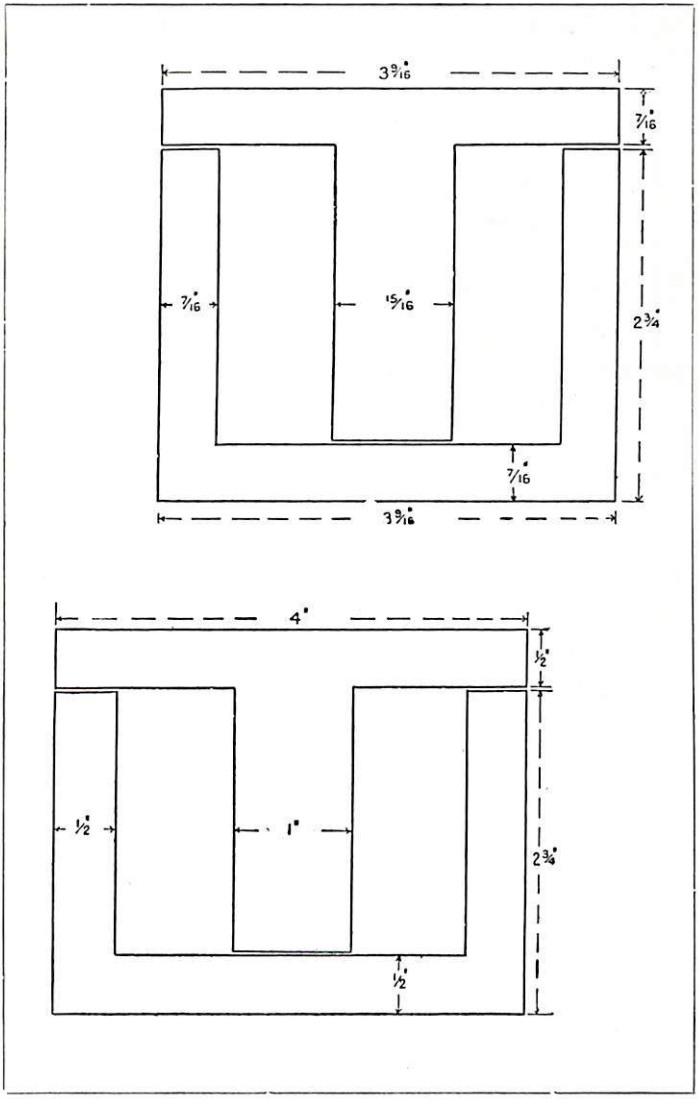


FIG. 85 (*continued*).

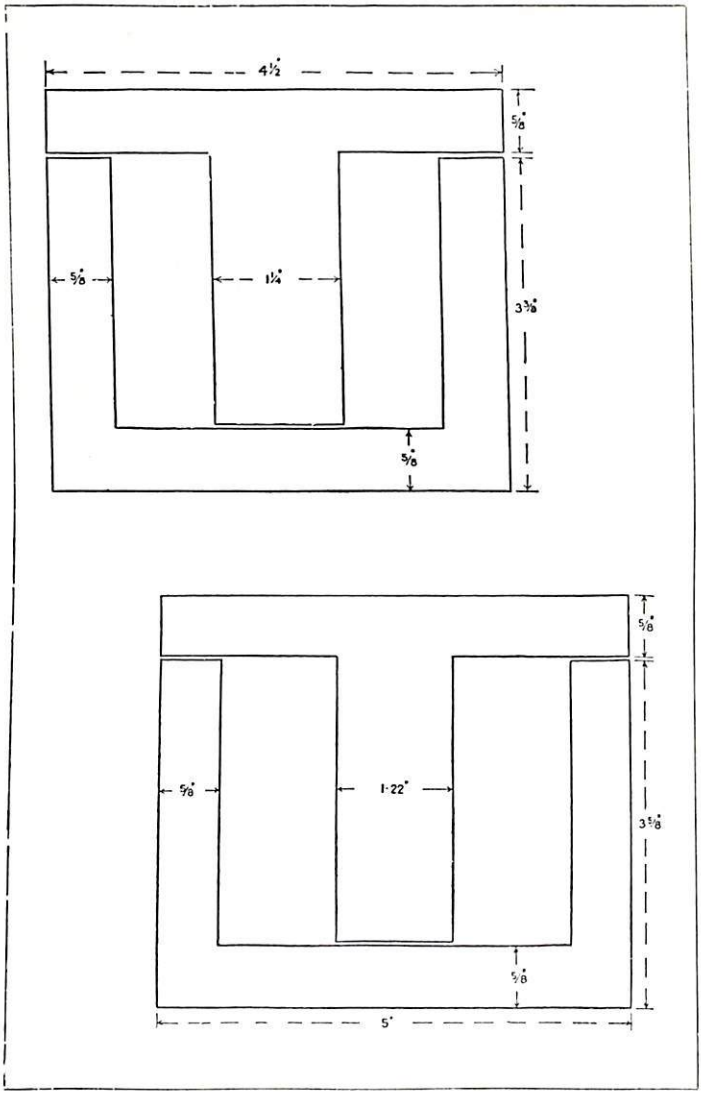


FIG. 85 (*continued*).

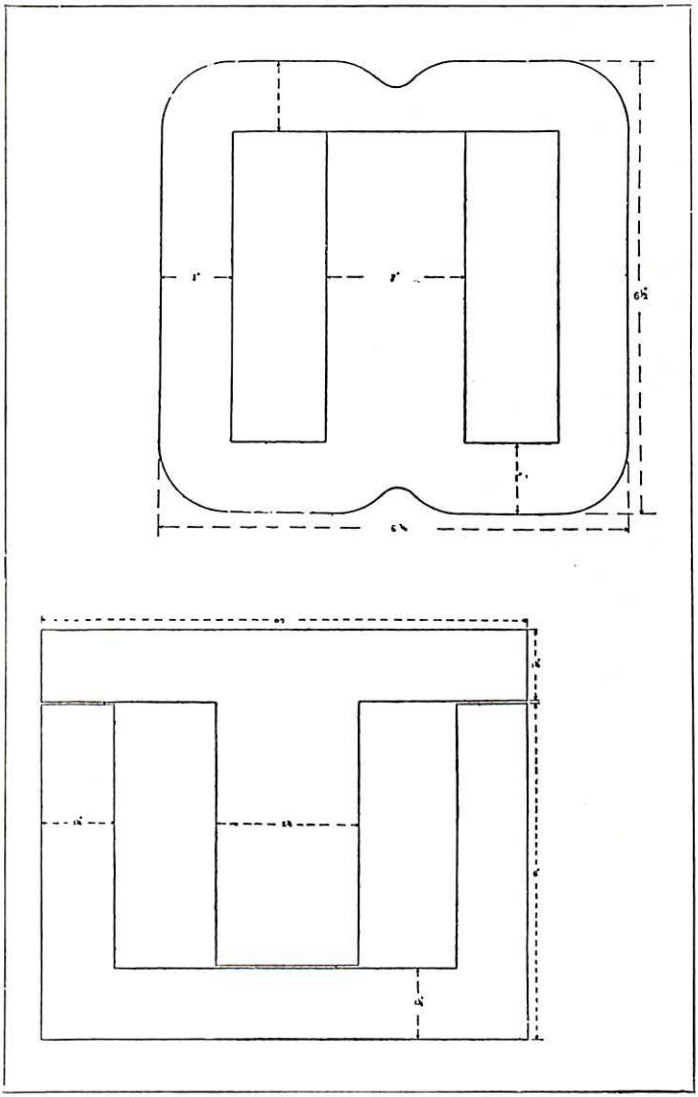


FIG. 85 (*continued*).

actually be 0·63 × 1·09 = 0·69 amperes. It would be permissible to use 23 S.W.G. wire for this current, since the extra, 0·01 ampere, is too small to matter. The efficiency of the transformers dealt with here would range from 80 per cent. in the smallest sizes to 96 per cent. in the largest.

Winding Area.

When the number of turns and the gauges of the wires to be used have been found, the next step is to calculate the area of the opening, or window, in the stampings which the winding will occupy. The values of winding area given in Table IX may be taken as a rough guide. Since the winding area varies considerably with the gauges of wires used in the coils it is not possible to fix a definite value for each size of transformer. It is advisable, therefore, to check the value given in Table IX to ensure that it is not too small.

How to Check the Winding Area.

For the transformer which is being considered as an example, this is done as follows:

The primary winding has 920 turns of 23 S.W.G. enamel covered wire. From Table XI it is seen that this gauge of wire winds 1,510 turns per square inch. The area occupied by the primary is therefore:

$$\frac{920}{1{,}510} = 0{\cdot}61 \text{ square inch.}$$

Similarly, the 45-volt winding, which has 189 turns of 17 S.W.G. double silk covered wire, has a winding area of:

$$\frac{189}{272} = 0{\cdot}7 \text{ square inch.}$$

The 1·8 volt winding, which will occupy less than one layer, will take up about 0·09 square inch if the length of the winding space is 1 inch. The total winding area is now:

$$0{\cdot}61 + 0{\cdot}7 + 0{\cdot}09 = 1{\cdot}4 \text{ square inches.}$$

It is now necessary to add about 20 per cent. allowance for the insulation between the layers, the space occupied by the bobbin and insulation between the windings. The area now becomes:

$$1{\cdot}4 \times 1{\cdot}2 = 1{\cdot}68 \text{ square inches.}$$

The Size of Stampings.

When the area of the core has been found from Table IX and the winding area has been calculated as in the previous paragraph, it is now possible to determine the size of stampings.

The best shape for the core would be cylindrical, but as this is not practicable with flat stampings, the next best shape, square, is used whenever possible. Table X gives the sizes and quantities of stampings for various core sections within the range of transformers under consideration.

It is not always possible to find standard stampings which will give a square core for any particular area, so that one of two alternatives are adopted.

The first is to make the core from strips of stalloy of the width shown in column 7, Table X. The other way is to make the core section rectangular by using stampings with a narrower tongue than is specified.

Suppose for the example transformer it is decided to use the stampings shown in Fig. 84 as these are a standard product easily obtainable. The width of the core is $\frac{15}{16}$ inch and the thickness of the stampings is

0·014 inch, so that the quantity of the stampings is given by:

$$\frac{A}{w} \times 71{\cdot}4$$

where A is the area of the core and w the width of the tongue of the stampings. This works out at 133 stampings in the present example.

The thickness occupied by the stampings is found from:

$$\frac{A}{w} \times 1{\cdot}11.$$

This gives a thickness of 2·07 inches for the example under consideration. The actual size of the core is therefore $\frac{15}{16} \times 2{\cdot}07$ inches. A bobbin with a hole $1 \times 2\frac{1}{8}$ inches would be quite suitable to accommodate this.

Centre-tapped Windings.

A full wave valve rectifier requires a centre-tapped winding of approximately twice the total voltage of the rectifier output voltage. A 500-volt direct-current rectified output from a valve rectifier would require a 1,000-volt centre-tapped high-tension winding on the transformer. This winding, however, does not carry the full current. Each half of the winding carries half the value of the current output of the rectifier. Suppose a rectifier is to have an output of 500 volts, 100 milliamperes. The high-tension winding on the transformer is then wound for 1,000 volts, 50 milliamperes, with a centre-tapping.

Useful Formulæ.

The following formulæ are useful in connection with the design of power transformers:

If v = Voltage of winding
f = Frequency of supply mains
T = Total turns of winding
A = Area of core transformer in square inches
B = Maximum flux in core (lines per square inch), then:

$$v = \frac{4{\cdot}44fTAB}{10^8}.$$

A satisfactory value for B, when stalloy is used, is 65,000 lines per square inch.

If t = turns per volt, the above formula may be simplified to:

$$t = \frac{14}{A} \text{ for 25 cycles.}$$

$$t = \frac{8{\cdot}75}{A} \text{ for 40 cycles.}$$

$$t = \frac{7}{A} \text{ for 50 cycles.}$$

$$t = \frac{5{\cdot}85}{A} \text{ for 60 cycles.}$$

If t = turns per volt
vI = output in volt-amperes,

then the approximate winding area is given by:

Winding area = tvI × 0·00254 square inch, or:

$$v\text{I (output)} = \frac{\text{Winding area} \times 394}{t}.$$

From the last formula it is possible to estimate the approximate output obtainable from a particular assembly of stampings.

Calculating Resistance of a Transformer Winding.

The resistance of a transformer winding is calculated from the following formula :

If t = Length of mean turn inches
T = Total turns of winding
r = Resistance of wire per yard in ohms
R = Resistance of coil in ohms, then

$$R = \frac{t \times T \times r}{36}.$$

Finding the Length of the Mean Turn.

The length of the mean turn may be found in two ways. The first is to set out the section of the winding to scale and measure it. A quicker way is to measure the length of a turn in the first layer before commencing the winding, then wind on the calculated number of turns. Now measure the length of a turn in the final layer. Half the sum of the two values obtained gives the length of the mean turn.

CHAPTER VII

THE CONSTRUCTION OF SMALL POWER TRANSFORMERS

The Essentials of a Transformer.

A TRANSFORMER consists essentially of a primary winding, and a secondary or output winding wound on an iron core which forms part of a closed magnetic circuit. The primary winding is connected to the supply mains and the secondary or output winding to the apparatus for which it is designed.

Power is transmitted from the primary winding to the secondary winding whenever a current is drawn from the secondary. When there is no current in the secondary winding, the power taken from the supply mains by the primary winding is negligible in small transformers. Therefore a transformer primary may be permanently connected to the supply mains without any appreciable power consumption.

THE USES OF SMALL TRANSFORMERS

Transformers are used to convert the voltage of an alternating current supply to any desired value. Thus a supply of 200 volts may be stepped up to 1,000 volts or reduced to 2 volts, without any appreciable loss of power. Static transformers, as they are called, can be used only on alternating current, the output is also

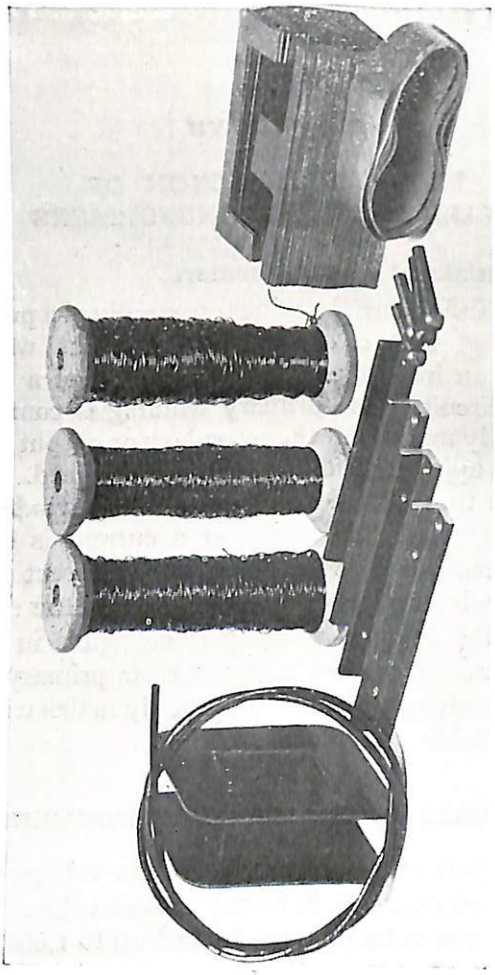


FIG. 86.—THE ESSENTIAL COMPONENTS USED FOR THE CONSTRUCTION OF THE TRANSFORMER FOR A HIGH-TENSION ELIMINATOR.

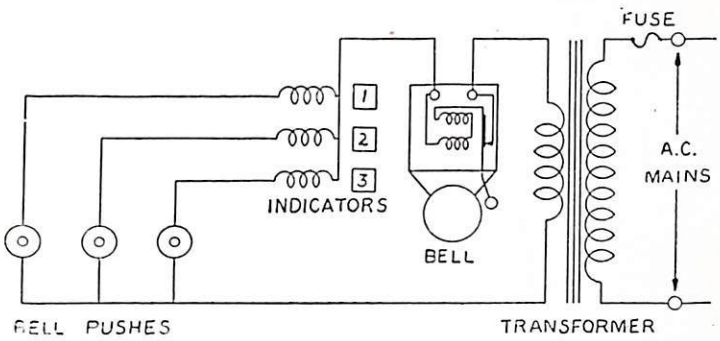


FIG. 87.—CIRCUIT DIAGRAM OF AN ELECTRIC BELL INSTALLATION.
Showing the use of a small power transformer to enable the system to be worked from the supply mains.

alternating and requires rectifying if it is to be used for charging accumulators, for operating electro-magnets or for supplying high tension to wireless sets. A transformer isolates the supply mains from the secondary circuit, because the primary and secondary windings are electrically insulated from one another.

Bells and Alarms.

Small electric bells may be worked on alternating current equally as well as on a direct current supply from batteries. Where the house supply is alternating the wet batteries may be replaced by a small transformer, thus saving the trouble and expense of reconditioning the batteries at regular intervals, besides giving a more reliable service. Although small bells may be obtained for working directly off the supply mains, the use of a transformer with a low voltage bell permits the existing wiring to the pushes and indicators to be used. If battery-operated bells are replaced by mains-operated types, the wiring must be renewed. A

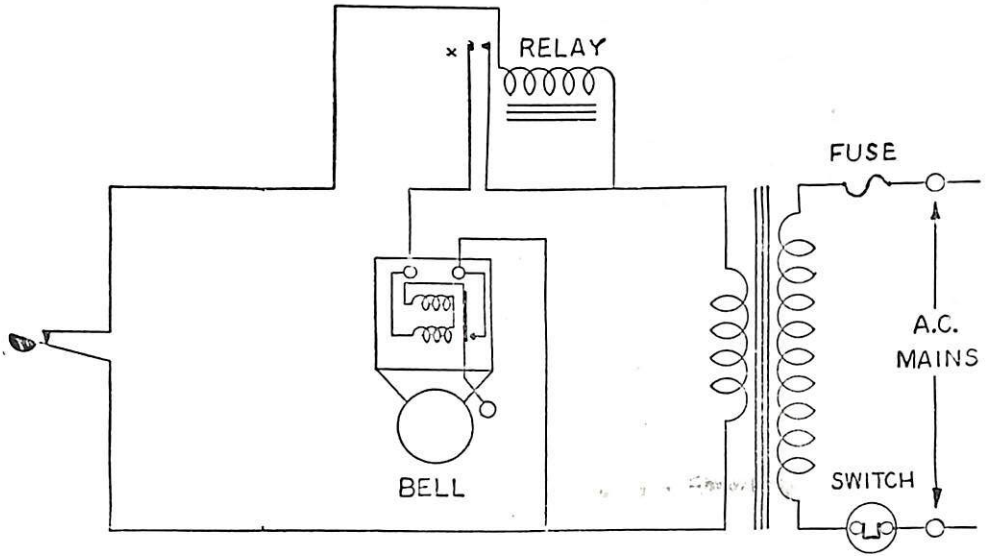


FIG. 88.—WIRING DIAGRAM OF A CLOSED CIRCUIT FIRE OR BURGLAR ALARM SYSTEM.

A switch is provided in the primary circuit to prevent the bell ringing during the daytime. The relay, when energized, keeps the contacts X apart. When the alarm contact is broken the bell circuit is completed through X.

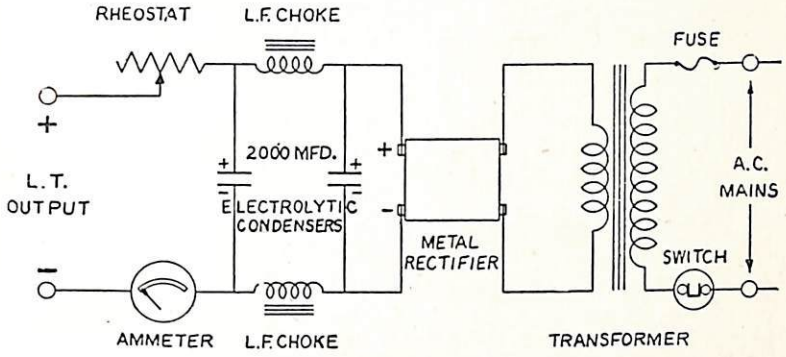


FIG. 89.—CIRCUIT DIAGRAM SHOWING THE APPLICATION OF A SMALL POWER TRANSFORMER IN A LOW-TENSION ELIMINATOR.

This is an eliminator giving a smoothed output of about 6 volts 1 ampere with a Westinghouse Style L T.4 rectifier and the 8-volt tapping on the bell transformer described here. The chokes are 0·05 to 0·1 henry at 1 ampere, depending on the degree of smoothing required.

big saving is effected by using a transformer in place of batteries on closed circuit fire and burglar alarms where a current flows continuously.

Bell and Alarm Circuits.

Fig. 87 shows the circuit of a bell installation using a transformer in place of batteries. When installing the transformer it is only necessary to remove the batteries and connect the secondary terminals of the transformer to the two wires formerly connected to the batteries and run two leads from the lighting circuit to the primary of the transformer. The application of a small transformer for working a closed circuit fire or burglar alarm system is shown in Fig. 88. A fuse is put in the primary circuit of the transformer in each case, as a safeguard, should the transformer break down. As the secondary winding has no electrical connection with the supply mains, there is no fear of shocks from any part of the system.

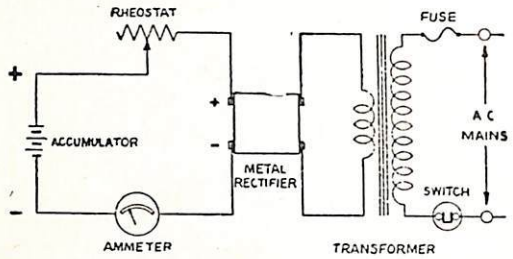


FIG. 90.—AN ACCUMULATOR CHARGING CIRCUIT.

Showing the use of a small transformer in conjunction with a Westinghouse Style A4 rectifier. With the transformer giving an output of 12–14 volts at 2 amperes, this arrangement will charge an 8-volt battery. The rheostat is 10 ohms max., and the ammeter a moving-coil type.

Toy Motors, Model Locomotives and Direct-Current Low Tension for Wireless.

Miniature electric motors with laminated field magnets may be run on alternating current as well as from batteries. Shunt-wound motors, and motors with permanent magnet or solid iron fields cannot be run satisfactorily on alternating current. A rheostat may be used for regulating the speed in the same way as it is used when the motor is driven from batteries. Alternating current is not suitable for working model locomotives incorporating automatic reversing gear.

Motors which are suitable for direct-current operation only may be worked from an alternating-current supply by using a rectifier and smoothing devices which convert the alternating current into direct current. The circuit of a low-tension battery eliminator is shown in Fig. 89 This is suitable for operating small motors and electric locomotives as well as supplying current for battery heated valves of wireless sets. The meter shown in the diagram is not essential for working toy motors, although its use will show when the rectifier is overloaded. For operating valves a meter is essential

to set the rheostat so as to obtain the correct working current for the filaments.

Accumulator Charging.

Fig. 90 shows a circuit for charging accumulators from alternating-current mains. It incorporates a transformer giving an output of 14 volts 2–3 amperes, the construction of which is described here. For a 2-ampere output a Westinghouse metal rectifier style A4 is used. The rheostat is about 10 ohms maximum resistance and the ammeter is a moving-coil type. This arrangement will charge four cells in series, that is, an 8-volt battery. A fuse and a switch is included in the primary circuit of the transformer. Although a fuse may also be put in the charging circuit, it is not essential because any extra current which flows in the secondary circuit causes a proportional increase in the flow of primary current.

High-Tension Supply for Wireless.

A transformer is used in high-tension eliminators for working on alternating-current mains. By this means any desired high-tension voltage may be obtained from any voltage of supply, whereas the output voltage of a direct-current eliminator is limited to that of the supply. The character of the secondary winding on the transformer depends on which type of rectifier is used. A metal rectifier requires only one secondary winding of approximately the same voltage as the direct-current output for both full-wave and for half-wave rectification. On the other hand, a valve rectifier requires a double voltage centre-tapped secondary winding for full-wave rectification and also an extra winding for the filament of the valve. The

half-wave valve rectifier requires only a single winding for the high tension in addition to the filament winding.

All-Mains Wireless Sets.

The transformer in an alternating-current all-mains wireless set has more than one secondary winding. There is the high-tension winding for supplying the plate current to the valves and also one or more windings for the valve filaments or heaters. There may also be a separate winding for supplying the grid-bias voltages, but it is more usual to obtain the grid bias from the voltage drop on resistance inserted in the negative high-tension leads.

Small Lamps.

Miniature electric lamps for decorative purposes may be worked from the mains by using a small transformer. The lamps are connected in series and the voltage of the transformer secondary is designed to give the voltage of one lamp multiplied by the total number in series. That is to say, if eight 3·5 volt 0·15 ampere bulbs are connected in series the transformer is required to give an output of 28 volts at 0·15 ampere. A small transformer is used when a very low power lamp is required, because high voltage lamps cannot be made below about 15 watts for 100-volt supplies and 25 watts for 200 volts.

HOW TO MAKE A SMALL TRANSFORMER

The smallest of three useful transformers described here is dealt with in detail to show how a transformer can be made when the necessary data is available. The principles of construction of all small transformers is the same, but they differ in such details as the size

of stampings, number of turns and arrangement of windings. Where there are several secondary windings and the size of the stampings permits, the different windings are divided into two or more sections on separate bobbins so as to obtain the best linkage between the windings.

Material for Bell Transformers.

The materials for small transformers are obtainable in several standard sizes. The different sizes of stampings and bobbins are known by numbers, but, as different manufacturers use different notation for the same thing, the actual sizes are given in the schedules. For the smallest transformer, with an output of 4–6 or 8 volts at 1 ampere, the following material is used:

40 pairs of No. 15 "Stalloy" stampings, 0·014 inch thick (window $1\frac{1}{2} \times \frac{3}{4}$ inches, middle limb $\frac{5}{8}$ inch wide).

1 bakelite bobbin No. 15 with $\frac{5}{8}$-inch square hole.

8 oz. of 20 S.W.G. enamel-covered copper wire for secondary.

6 oz. of enamel-covered copper wire for primary, the size depending on the mains voltage (see table).

1 pair of cast clamps or 16 inches of $\frac{1}{2} \times \frac{1}{2}$ inch angle iron.

4 steel 2B.A. screws 1 inch long for clamps.

Short lengths of 0·75 mm. systoflex, and empire cloth $1\frac{1}{2}$ inches wide.

6 terminals and ebonite or bakelite terminal block.

The Primary Winding.

The size of wire and the number of turns put on the primary winding depend on the voltage and fre-

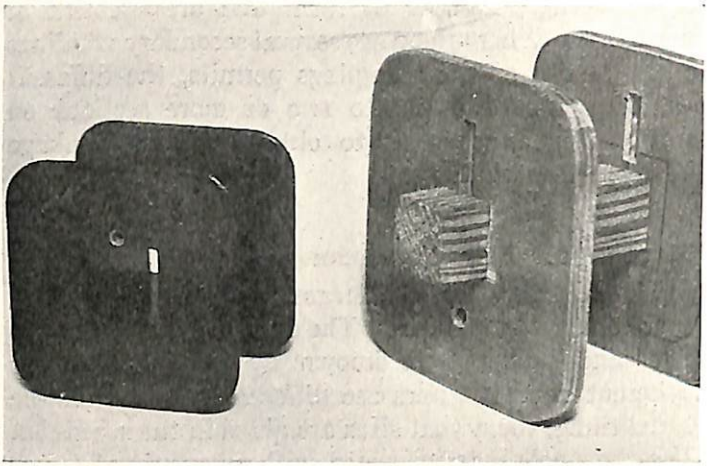


FIG. 91.—THE BLACK BAKELITE BOBBIN OF THE BELL TRANSFORMER.

Showing the wooden winding jig used to support the bobbin during winding. Note the hole in the bobbin for the start of the primary winding. The size of the holes in the bobbin cheeks should be such that the systoflex sleeving fits in them.

quency of the supply. The table below gives the necessary data for 50-cycle supplies (the standard frequency), also the maximum primary current, which it is necessary to know when a fuse is included in the primary circuit.

Supply (Volts).	Maximum Primary Current (Amperes).	No. of Turns.	S.W.G.
100	0·1	2,000	32
110	0·091	2,200	33
120	0·083	2,400	33
200	0·050	4,000	36
210	0·048	4,200	36
220	0·045	4,400	36
230	0·043	4,600	37
240	0·042	4,800	37
250	0·040	5,000	37

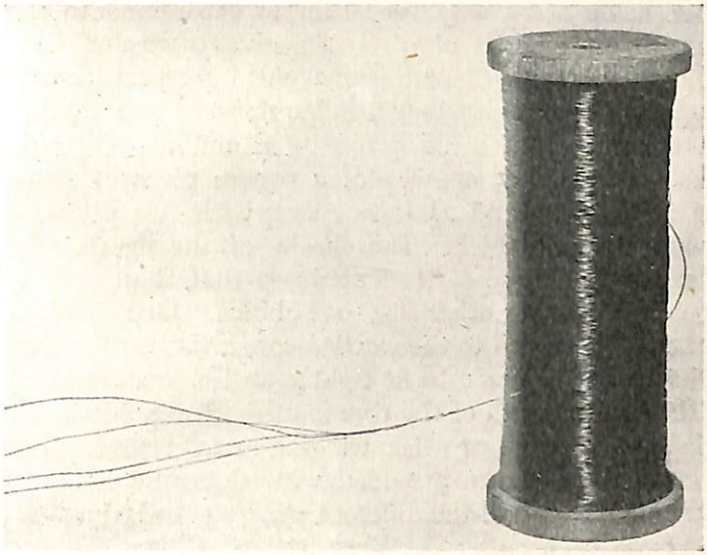


FIG. 92.—PREPARING THE WIRE FOR WINDING.

Before the wire is started on the fine wire coils, a four-strand lead is formed on the end of the wire.

Where the voltage of the supply is different from any of the values given in the table, the number of turns may be estimated by multiplying the voltage by twenty. If the frequency is higher than 50, less turns are necessary. Thus, if the frequency is 100, half the number of turns are required, because the reactance is directly proportional to the frequency. For a lower frequency, such as 25 cycles, a larger iron core must be used or the number of turns becomes excessive with consequent high copper losses.

Winding Jig.

Before commencing the winding a wooden jig is made to support the bakelite bobbin. These bobbins

are made necessarily very thin to accommodate the maximum amount of wire on a given core and they must be provided with some extra support during winding or the cheeks will bulge out and prevent the stampings from being properly assembled. The jig shown in Fig. 91 consists of a square piece of wood $\frac{5}{8}$ inch square and $2\frac{1}{2}$ inches long with two plywood cheeks $\frac{1}{4}$ inch thick. The cheeks of the jig may be larger than those of the bobbin so that the same jig may be used for other sizes of bobbins. One cheek of the jig is screwed to the wooden core and the other has a square hole made to fit tightly on the wooden core. The excess length of the core is utilized to hold the jig in a lathe chuck or other winding arrangement. The wooden cheeks are provided with slots and holes to enable the ends of the different windings to be brought out where necessary. When the winding has been made the removable cheek is taken off and the bakelite bobbin pushed into position and the cheek replaced and firmly pressed home. If the removable cheek is not a tight fit on the core, two screws are put in to hold the cheek firmly against the bobbin. Before winding the bobbin make sure that it is not oversize or the stampings will not close up properly.

Winding the Primary.

The primary winding is put on first, because as it is a fine wire coil the length of the turns must be kept as short as possible to minimize the losses due to the higher resistance of the wire. The primary is also wound close to the core to obtain the maximum choking effect when the transformer is unloaded. Before starting the actual winding a flexible lead is formed on the end of the wire. This is done by doubling a length

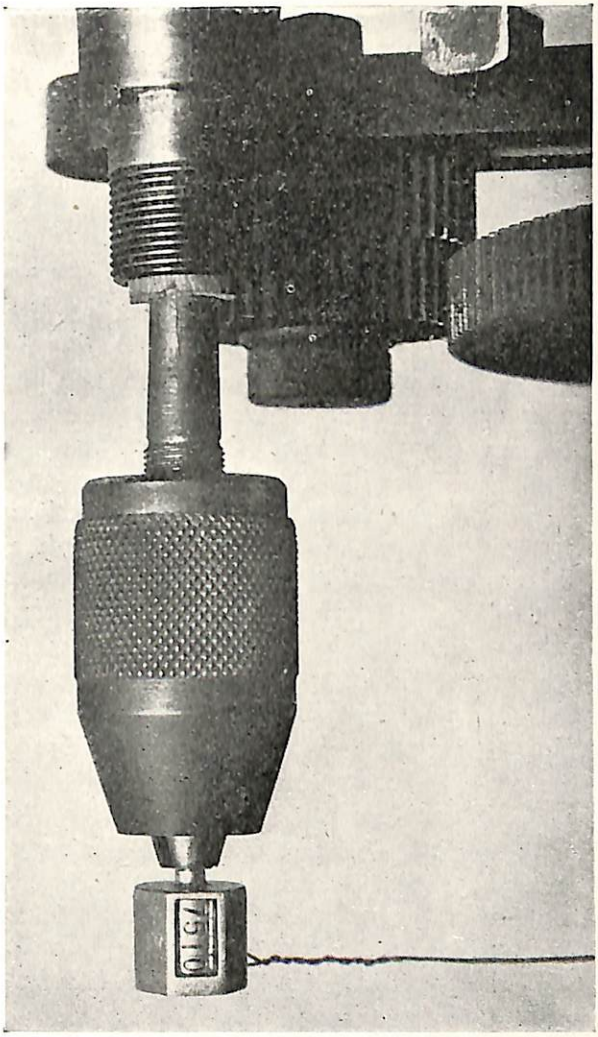


FIG. 93.—A SIMPLE METHOD OF MOUNTING A COUNTER ON THE LATHE.
This is to count the turns as they are wound on.

of the wire twice and soldering the ends together as shown in Fig. 92. It is essential to do this to provide a strong flexible lead which will not easily break off at the entrance to the hole in the cheek of the bobbin. The next step is to draw the flexible end of the wire through the hole in the bobbin shown in Fig. 91 so as to leave just less than one turn of the four-strand wire inside the bobbin. The soldered joint is then insulated with a small channel of empire cloth and the winding commenced.

Some difficulty may be experienced at first in keeping the turns even on the square core when the winding is done by hand, but after the first few layers and paper insulation has been put on, the winding becomes more rounded and easier to handle. Once the knack has been accomplished it will be found easier to keep the winding even if the bobbin is revolved at a good speed, although when the wire does run back there is more to unwind. It is essential to keep the turns side by side and to put thin (1½ mils) paper between each layer for high-voltage coils. Pay particular attention to the ends of the layers. Much space is wasted if the paper is cut too long, and the end turns will slip down to preceding layers if the paper is cut too short.

Counting the Turns.

This is the most trying part of the job if a counter is not available. Fig. 93 shows how an improvised counting arrangement may be attached to the back end of a lathe headstock. A chuck is fixed in the hollow spindle and the countershaft is held in the chuck. A length of wire twisted round the counter base and fastened to the nearest fixed point is all that is required to prevent the counter from twisting round. A cyclo-

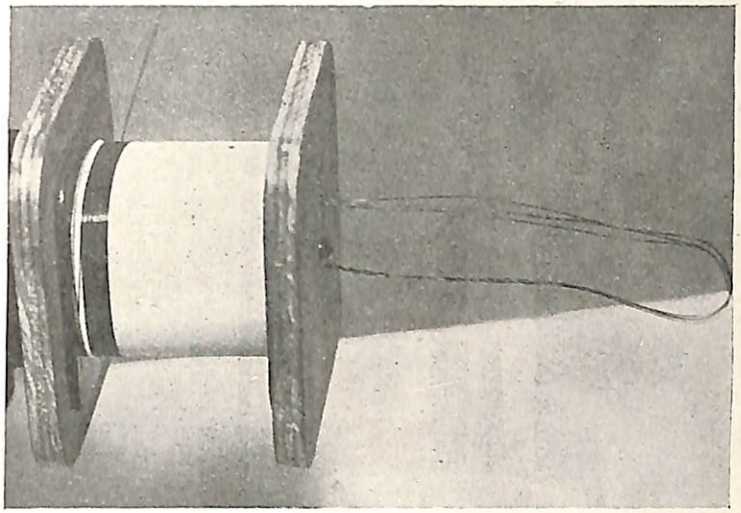


FIG. 94.—FINISHING OFF THE PRIMARY WINDING (1).

The last few turns of the primary winding frequently only partly fill a layer, but this does not matter. Note the use of a sheet of white paper underneath the bobbin to provide a contrast with the black wire and make it easy to follow.

meter may be used for this, if the ratio is determined beforehand, as these counters make several revolutions to each integer. It is very important to count the turns accurately.

Finishing the Primary.

It almost invariably happens that when the correct number of turns is reached the final layer of wire is only partly wound as shown in Fig. 94. This does not matter. When this stage is reached the last turn is unwound and a stranded lead is formed on the end of the wire and one turn of the lead is put back on the winding after insulating the soldered joint, as shown

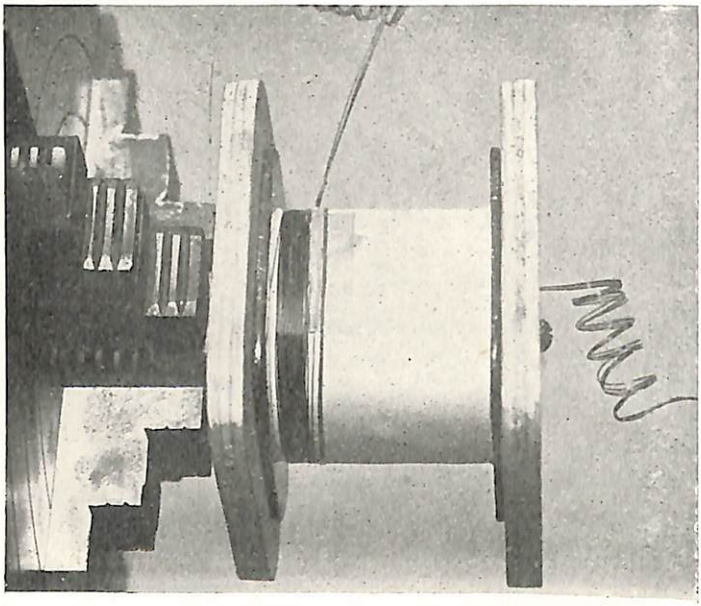


FIG. 95.—FINISHING OFF THE PRIMARY WINDING (2).

This is done with a four-strand lead. Note how the empire cloth, which is used to cover the soldered joint, is tied down with silk thread.

in Fig. 95. The finishing end of the primary is brought out through a hole in the cheek of the bobbin. The two ends of the primary are brought through the opposite cheeks, but on the same side of the coil. When the primary has been finished off two layers of empire cloth are put on to insulate it from the secondary, which is now wound on.

Winding the Secondary.

The secondary winding is started through a hole in the bobbin check, but there is no need to provide multi-strand leads with this thick gauge. The total

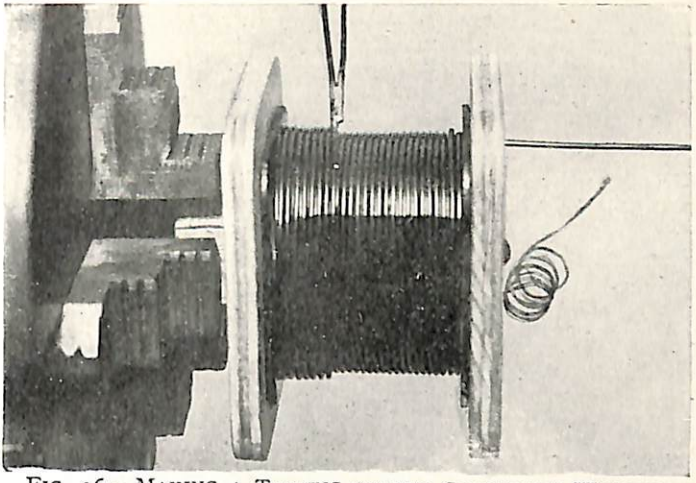


FIG. 96.—MAKING A TAPPING ON THE SECONDARY WINDING OF THE BELL TRANSFORMER.

This is done by soldering a lead on to the wire without cutting the winding.

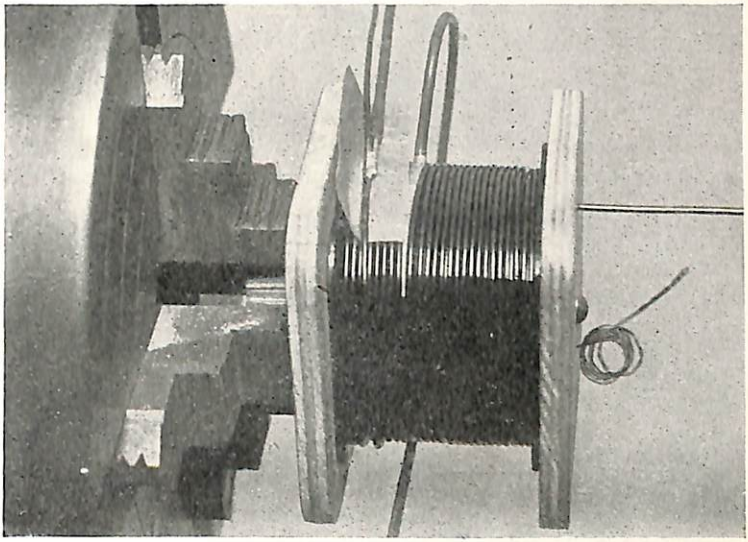


FIG. 97.—HOW THE JOINT OF THE SECOND TAPPING IS INSULATED WITH EMPIRE CLOTH.

Note how the first tapping has been wound in.

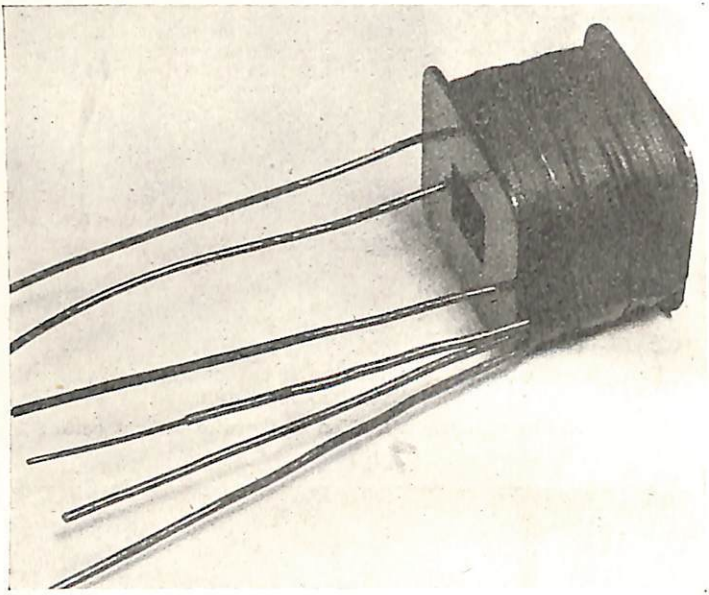


FIG. 98.—THE FINISHED BOBBIN.

Taped up with the leads covered with 0·75 mm. systoflex sleeving, ready to receive the stampings.

number of turns for 8 volts is 170. When 85 turns have been put on, a lead is soldered on as shown in Fig. 96. After insulating the joint the winding is carried on, winding on either side of the lead. Fig. 97 shows the second tapping, at the 127th turn, being insulated. A piece of 0·75 mm. systoflex is put on the lead as far down as it will go and the joint is then lapped with empire cloth. This method of making the tappings on a winding of few thick turns is more economical of space than when each tapping is brought through the bobbin cheek.

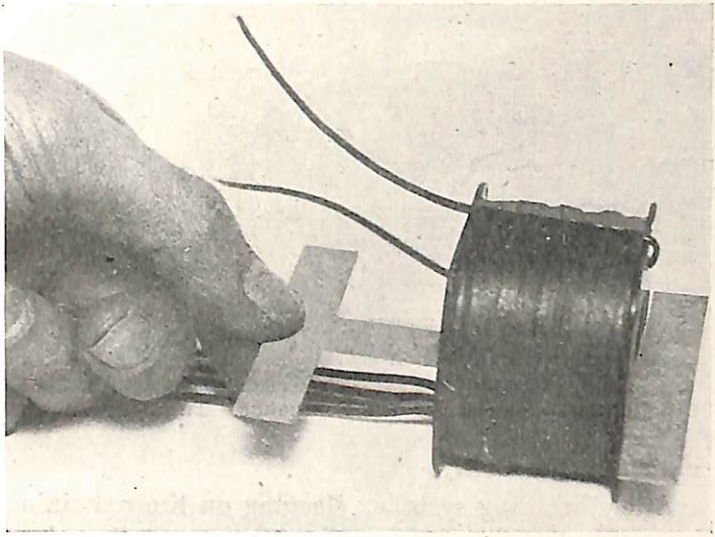


FIG. 99.—ASSEMBLING THE STAMPINGS. FIRST STAGE.

Take care to keep the paper-covered sides of the stampings all the same way up.

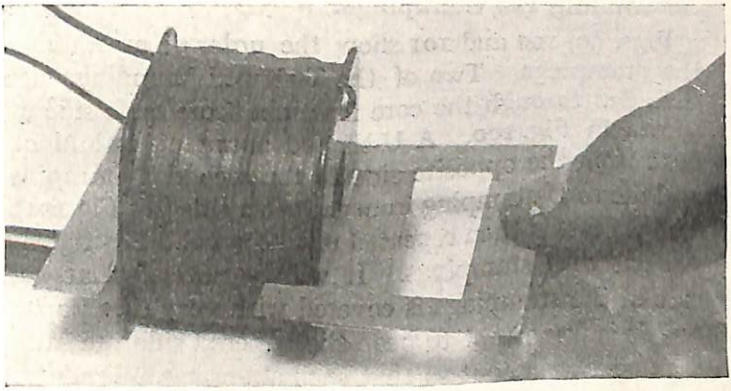


FIG. 100.— ASSEMBLING THE STAMPINGS. SECOND STAGE.

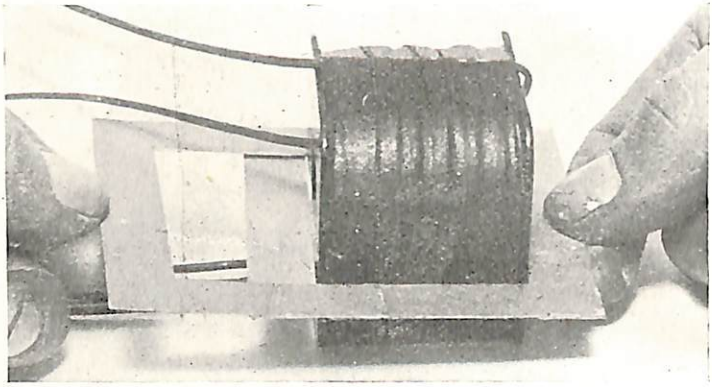


FIG. 101.—ASSEMBLING THE STAMPINGS. THIRD STAGE.

Finishing the Coil.

After threading systoflex sleeving on the remaining leads, the secondary leads are bent back over the winding and the coil taped up with empire cloth or black tape as shown in Fig. 98. The bobbin is now ready to receive the stampings.

Assembling the Stampings.

Figs. 99, 100 and 101 show the order of assembling the stampings. Two of the T-shaped stampings are threaded through the core first, one from each side as shown in Fig. 100. A U-shaped stamping is laid on next from the opposite side to the second T-stamping and then a U-stamping from the other side (see Fig. 101). The process is then repeated until the bobbin is tightly packed with stampings. It will be noticed that one side of the stampings is covered with very thin paper, and it is important to keep the papered side the same way up throughout so that each stamping is insulated from the next. The purpose of laminating would be

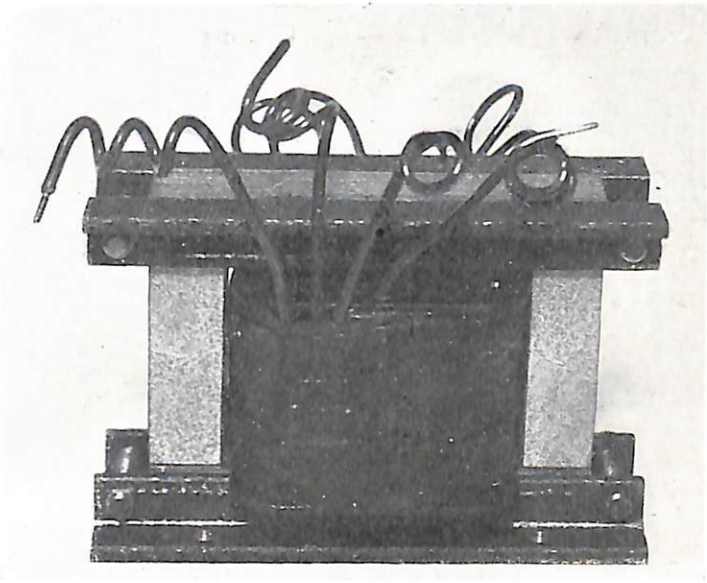


FIG. 102.—THE FINISHED TRANSFORMER PROVIDED WITH FLEXIBLE LEADS IN PLACE OF TERMINALS.

This method is adopted when the transformer is to be permanently wired to other apparatus.

nullified if there were no insulation at all between the leaves. For most uses the black oxidized surface of the metal provides sufficient insulation between the laminations.

The object of laminating the iron core is to minimize the eddy currents which would otherwise be set up in the core by the rapidly alternating flux.

Clamps.

When the stampings have been assembled and carefully tapped square and level, a pair of clamps are screwed on to hold the stampings rigid. Fig. 102 shows

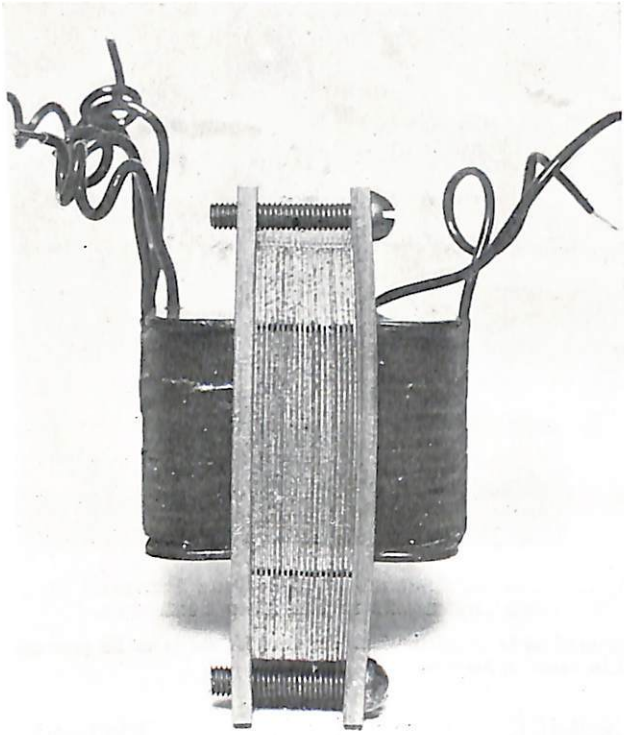


FIG. 103.—HOW NOT TO CLAMP THE STAMPINGS.

The use of flat strips should be avoided. When tightened up the flat strips bend and produce an unsightly job. This illustration also shows the result of using a bobbin too big for the stampings or allowing the winding to spread the cheeks of the bobbin. The stampings do not close up properly.

the bell transformer finished off with clamps made from $\frac{1}{2} \times \frac{1}{2}$ inch angle-iron $\frac{1}{8}$ inch thick. Nuts may be used instead of tapping a thread in the clamps. One pair of the clamps is provided with fixing holes and the terminal block, if required, is screwed to the top pair of clamps or fixed between the ends of the clamp.

When the transformer is mounted with the longest side horizontal with angle clamps, as shown in Fig. 102, the limbs of the outside U-stampings are not clamped, so that about two-thirds of the length is cut off. Rectangular clamps, which clamp all four sides of the stampings, are preferable because they prevent the stampings from bulging and so producing an unsightly job.

What to Avoid.

Do not use flat strips of metal to clamp the stampings. Fig. 103 shows the result of so doing. Although the strips shown are steel $\frac{1}{8}$ inch thick and $\frac{1}{2}$ inch wide they bend quite easily when tightened up and produce a very unsightly job. Fig. 103 also shows another defect caused by the cheeks of the bobbin not being properly supported when winding. They have bulged and prevent the stampings from being assembled properly, leaving a small air gap between each, which lowers the efficiency of the iron circuit.

Finishing Touches.

The clamps of the transformer should be enamelled, especially if they are made from angle iron ; green and black are suitable colours. The exposed edges of the stampings are given a coat of insulating varnish. Clear brushing cellulose is very suitable for this.

TRANSFORMER FOR LOW-TENSION CHARGER

Materials Required.

100 pairs of "Stalloy" stampings No. 30 (window $1\frac{1}{8} \times \frac{7}{8}$ inches, middle limb $\frac{15}{16}$ inch wide).

1 bakelite bobbin No. 4F, 1 × 1½ inches hole.
8 oz. of 18 S.W.G. enamel-covered copper wire for secondary.
9 oz. of enamel-covered copper wire for primary, size depending on the mains voltage (see table).
1 pair of cast clamps or 20 inches of angle iron ½ × ½ × ⅛ inch.
4 steel 2B.A. screws 1¾ inches long.
Short lengths of 0·75-mm. systoflex and empire cloth 1 inch wide.
4 terminals and ebonite or bakelite terminal block.

Primary Winding.

The following table gives the primary winding data for 50-cycle supplies, based on 6·5 turns per volt :

Supply (Volts).	Maximum Primary Current (Amperes).	No. of Turns.	S.W.G.
100	0·35	650	25
110	0·318	715	25
120	0·292	780	26
200	0·175	1,300	28
210	0·167	1,365	29
220	0·159	1,430	29
230	0·152	1,495	29
240	0·146	1,560	30
250	0·140	1,625	30

The Secondary Winding.

The secondary, which gives an output of a little over 12 volts at 2 amperes, consists of 91 turns of 18 S.W.G. wire wound without any tappings. There is no need to interleave paper between the layers of the secondary winding. The primary winding is wound on first in the same way as for the bell transformer.

" Manufacturer's Type."

If the transformer is to be permanently screwed into a box with the other charging gear there is no need to provide terminals. The leads from the bobbin are left long enough to connect directly to the rectifier and the mains terminals on the charger. The practice of using long leads direct from the bobbin in place of the familiar terminal block is the general practice in commercially made sets and, therefore, instruments finished in this style are known as " Manufacturer's Type."

TRANSFORMER FOR HIGH-TENSION ELIMINATORS

This transformer is designed to give a high-tension output of 135 volts at 30 milliamperes to feed a Westinghouse metal rectifier style H.T.15, which gives a direct-current output of 200 volts at 28–30 milliamperes. A low-tension winding is also included for heating mains valves. This winding gives an output of 4 volts at 2 or 3 amperes, depending upon whether a two- or three-valve set is being used.

Material Required.

The material used for the construction of this transformer is shown in Fig. 86. It is composed as follows:

100 pairs of " Stalloy " stampings No. 30 (window $1\frac{1}{8} \times \frac{7}{8}$ inches, middle limb $\frac{15}{16}$ inch wide).
1 bakelite bobbin No. 4F, 1 × $1\frac{1}{2}$ inches hole.
4 steel 2B.A. screws and a set of clamps.
Systoflex sleeving and a yard of empire cloth 1 inch wide.
4 oz. of No. 35 S.W.G. enamel-covered copper wire for the high-tension secondary winding.

8 oz. of No. 16 S.W.G. double silk-covered copper wire for the low-tension secondary winding.

8 oz. of enamel-covered copper wire, the gauge of which is found from the following table:

Supply (Volts).	Maximum Primary Current (Amperes).	No. of Turns.	S.W.G.
100	0·2	650	26
110	0·182	715	26
120	0·166	780	27
200	0·100	1,300	30
210	0·095	1,365	30
220	0·091	1,430	30
230	0·087	1,495	31
240	0·083	1,560	31
250	0·080	1,625	31

The Secondary Windings.

After winding the primary turns a layer of paper and a layer of empire cloth are put on to insulate the primary from the high-tension secondary. The high-tension secondary, consisting of 910 turns of 35 S.W.G. wire, is put on next and this insulated in the same way after winding the final layer.

Low-Tension Winding.

The low-tension or heater winding is wound on last. This consists of 27 turns of 16 S.W.G. double silk-covered wire for a 4 volt 2 ampere winding, or 28 turns of 16 S.W.G. for a 4 volt 3 ampere winding.

Minimizing Voltage Drop.

It will be noticed that the gauges of wire are very liberal on this design, and the transformer will actually

give a higher output quite safely. The object in using a heavier gauge than is necessary to carry the required current is to minimize the voltage drop in the windings, and so give a better regulation.

TABLE XII

THE PROPERTIES OF COPPER WIRES

S.W.G.	Dia., In. Bare.	Sectional Area, Sq. In. Bare.	Ohms per 1,000 Yd.	Enamelled.	
				Turns per Sq. In.	Lb. per 1,000 Yd.
16	0·064	$3·22 \times 10^{-3}$	7·463	219	37·67
17	0·056	$2·46 \times 10^{-3}$	9·747	286	28·82
18	0·048	$1·81 \times 10^{-3}$	13·267	388	21·18
19	0·040	$1·26 \times 10^{-3}$	19·105	550	14·74
20	0·036	$1·02 \times 10^{-3}$	23·59	670	11·96
21	0·032	$0·804 \times 10^{-3}$	29·85	850	9·46
22	0·028	$0·616 \times 10^{-3}$	38·99	1,110	7·26
23	0·024	$0·452 \times 10^{-3}$	53·07	1,500	5·34
24	0·022	$0·380 \times 10^{-3}$	63·16	1,800	4·94
25	0·020	$0·314 \times 10^{-3}$	76·42	2,150	3·72
26	0·018	$0·254 \times 10^{-3}$	94·35	2,650	3·02
27	0·0164	$0·211 \times 10^{-3}$	113·65	3,180	2·51
28	0·0148	$0·172 \times 10^{-3}$	139·55	3,900	2·05
29	0·0136	$0·145 \times 10^{-3}$	165·27	4,550	1·74
30	0·0124	$0·121 \times 10^{-3}$	198·8	5,550	1·43
31	0·0116	$0·106 \times 10^{-3}$	227·2	6,300	1·26
32	0·0108	$0·0916 \times 10^{-3}$	262·1	7,300	1·09
33	0·0100	$0·0785 \times 10^{-3}$	305·7	8,400	0·939
34	0·0092	$0·0665 \times 10^{-3}$	361·2	10,000	0·792
35	0·0084	$0·0554 \times 10^{-3}$	433·2	12,000	0·662
36	0·0076	$0·0454 \times 10^{-3}$	529·2	14,500	0·543
37	0·0068	$0·0363 \times 10^{-3}$	661·1	18,200	0·437
38	0·0060	$0·0283 \times 10^{-3}$	849·1	23,000	0·342
39	0·0052	$0·0212 \times 10^{-3}$	1,130·5	30,700	0·256
40	0·0048	$0·0181 \times 10^{-3}$	1,326·7	35,500	0·218
41	0·0044	$0·0152 \times 10^{-3}$	1,578·9	43,400	0·183
42	0·0040	$0·0126 \times 10^{-3}$	1,910·5	50,800	0·151
43	0·0036	$0·0102 \times 10^{-3}$	2,359	65,800	0·122
44	0·0032	$0·00804 \times 10^{-3}$	2,935	81,500	0·0971
45	0·0028	$0·00616 \times 10^{-3}$	3,899	104,000	0·0748
46	0·0024	$0·00452 \times 10^{-3}$	5,307	142,000	0·0547
47	0·0020	$0·00314 \times 10^{-3}$	7,642	197,000	0·0378

TABLE XII (*continued*)

THE PROPERTIES OF COPPER WIRES

S.W.G.	Single Silk.		Single Silk and Enamel.		Double Silk.	
	Turns per Sq. In.	Lb. per 1,000 Yd.	Turns per Sq. In.	Lb. per 1,000 Yd.	Turns per Sq. In.	Lb. per 1,000 Yd.
16	222	37·50	201	37·97	216	37·69
17	287	28·75	256	29·10	277	28·92
18	400	21·15	359	21·41	384	21·28
19	560	14·72	500	14·93	540	14·84
20	690	11·92	610	12·11	655	12·03
21	860	9·43	755	9·59	815	9·54
22	1,110	7·24	975	7·38	1,040	7·34
23	1,500	5·31	1,300	5·43	1,369	5·42
24	1,800	4·46	1,560	4·58	1,600	4·51
25	2,150	3·69	1,890	3·78	1,890	3·74
26	2,650	2·99	2,300	3·08	2,350	3·04
27	3,180	2·49	2,740	2·55	2,800	2·53
28	3,850	2·03	3,300	2·09	3,330	2·07
29	4,500	1·72	3,800	1·77	3,850	1·74
30	5,300	1·43	4,500	1·47	4,500	1·46
31	6,000	1·25	5,100	1·29	5,000	1·28
32	6,800	1·09	5,810	1·12	5,625	1·11
33	7,800	0·936	6,600	0·969	6,400	0·957
34	9,000	0·795	7,700	0·820	7,300	0·813
35	10,300	0·664	8,900	0·688	8,400	0·683
36	12,300	0·546	10,400	0·567	9,790	0·564
37	15,200	0·439	12,600	0·458	11,550	0·453
38	18,700	0·343	15,620	0·360	13,800	0·358
39	23,500	0·260	20,400	0·272	16,850	0·274
40	26,800	0·223	23,000	0·233	18,750	0·237
41	31,800	0·189	26,800	0·197	23,000	0·203
42	37,000	0·158	30,500	0·166	26,000	0·171
43	43,000	0·129	36,900	0·135	29,600	0·142
44	51,500	0·104	43,200	0·109	34,200	0·116
45	62,500	0·0818	51,500	0·0863	40,000	0·0929
46	77,000	0·0604	65,500	0·0636	47,000	0·0693
47	97,500	0·0435	81,700	0·0458	56,500	0·0515

TABLE XII (*continued*)

THE PROPERTIES OF COPPER WIRES

S.W.G.	Single Cotton.		Double Cotton (Special Fine).		Double Cotton (Ordinary).	
	Turns per Sq. In.	Lb. per 1,000 Yd.	Turns per Sq. In.	Lb. per 1,000 Yd.	Turns per Sq. In.	Lb. per 1,000 Yd.
16	199	38·15	181	38·65	171	38·96
17	250	29·34	235	29·76	222	30·08
18	330	21·71	318	22·06	286	22·28
19	450	15·16	430	15·33	384	15·79
20	560	12·36	540	12·47	450	12·80
21	690	9·84	650	9·92	565	10·23
22	860	7·62	815	7·68	730	7·95
23	1,180	5·58	1,040	5·65	860	5·75
24	1,370	4·70	1,180	4·79	975	5·00
25	1,600	3·91	1,370	3·99	1,110	4·18
26	1,880	3·21	1,600	3·28	1,370	3·46
27	2,180	2·69	1,820	2·75	1,550	2·93
28	2,550	2·34	2,100	2·78	1,760	2·43
29	2,900	1·88	2,350	1·93	1,960	2·09
30	3,300	1·57	2,650	1·65	2,400	1·81
31	3,600	1·39	3,080	1·46	2,600	1·57
32	4,000	1·22	3,540	1·29	2,830	1·40
33	4,400	1·07	3,900	1·14	3,080	1·24
34	4,950	0·902	4,300	0·962	3,450	1·08
35	6,500	0·766	4,800	0·829	3,700	0·951
36	7,400	0·624	5,400	0·705	4,100	0·745
37	8,500	0·512	6,400	0·584	5,200	0·620
38	10,000	0·409	8,200	0·476	5,900	0·507
39	11,800	0·322	9,600	0·384	6,700	0·414
40	12,900	0·282	10,400	0·344	7,200	0·370
41	—	—	—	—	—	—
42	—	—	—	—	—	—
43	—	—	—	—	—	—
44	—	—	—	—	—	—
45	—	—	—	—	—	—
46	—	—	—	—	—	—
47	—	—	—	—	—	—

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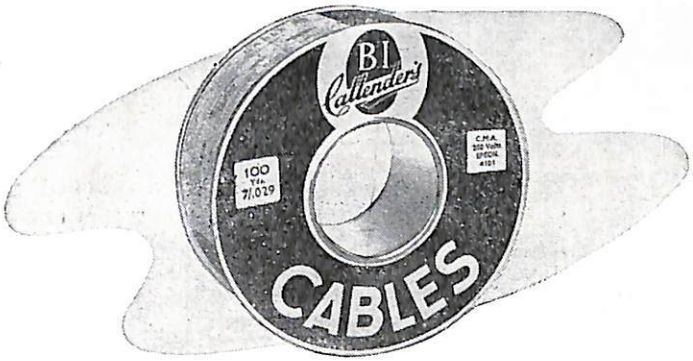

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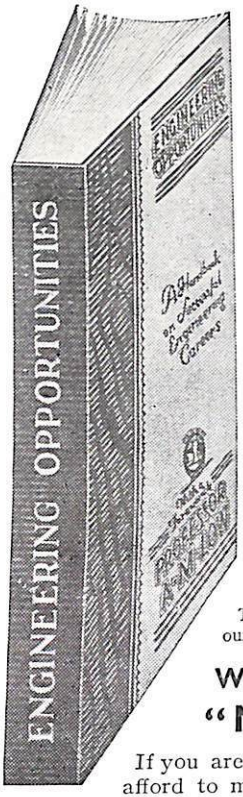

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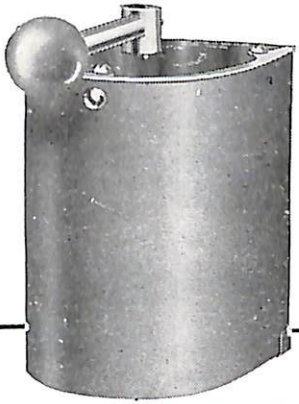

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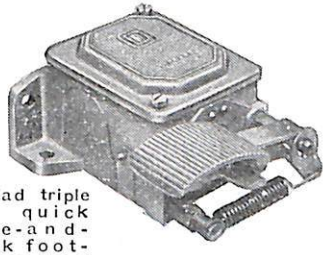

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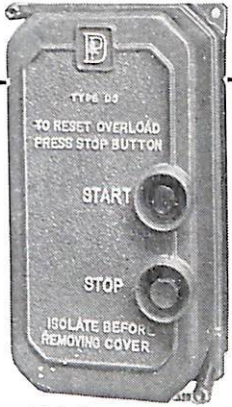

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